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# United States Patent [19]

Hughes et al.

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[54] NETWORK BASED TASK MANAGEMENT

[75] Inventors: Michael Hughes, Camarillo; Glen Gira, Northridge; Reed Wilcox, Burbank, all of Calif.

[73] Assignee: California Institute of Technology, Pasadena, Calif.

[21] Appl. No.: 593,260

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[51] Int. Cl.<sup>6</sup> H04B 10/20; G06F 15/73

[52] U.S. Cl. 705/8; 705/9; 705/11

[58] Field of Search 705/8, 9; 364/578, 364/468.03

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Primary Examiner—Kevin J. Teska

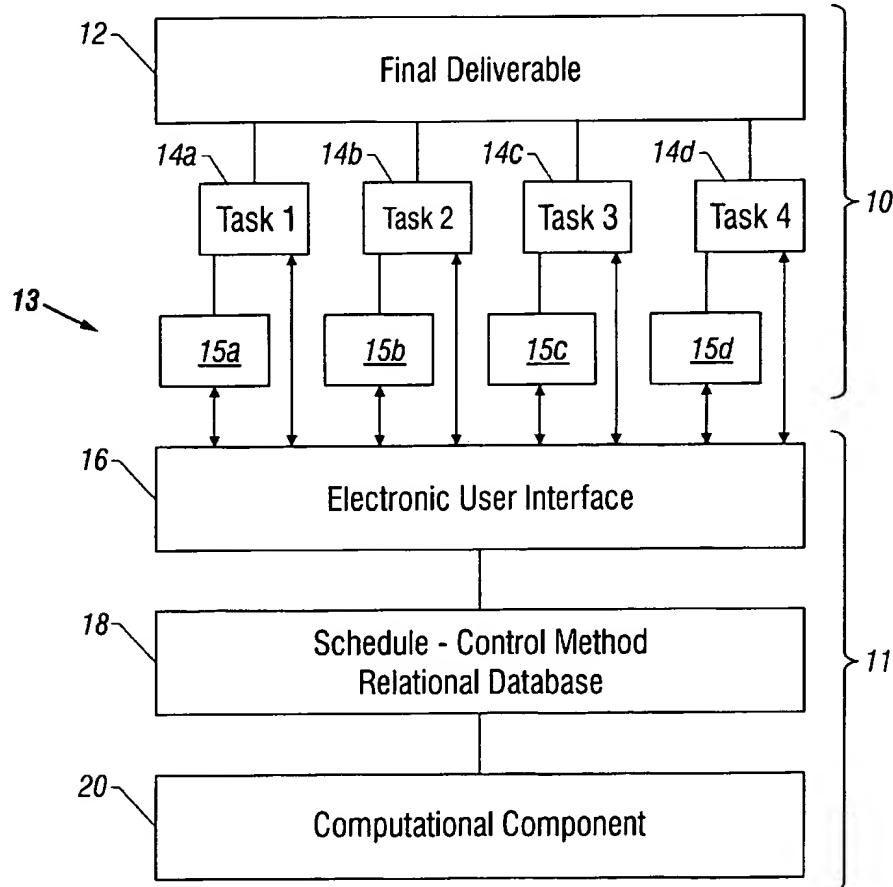
Assistant Examiner—Dan Fiul

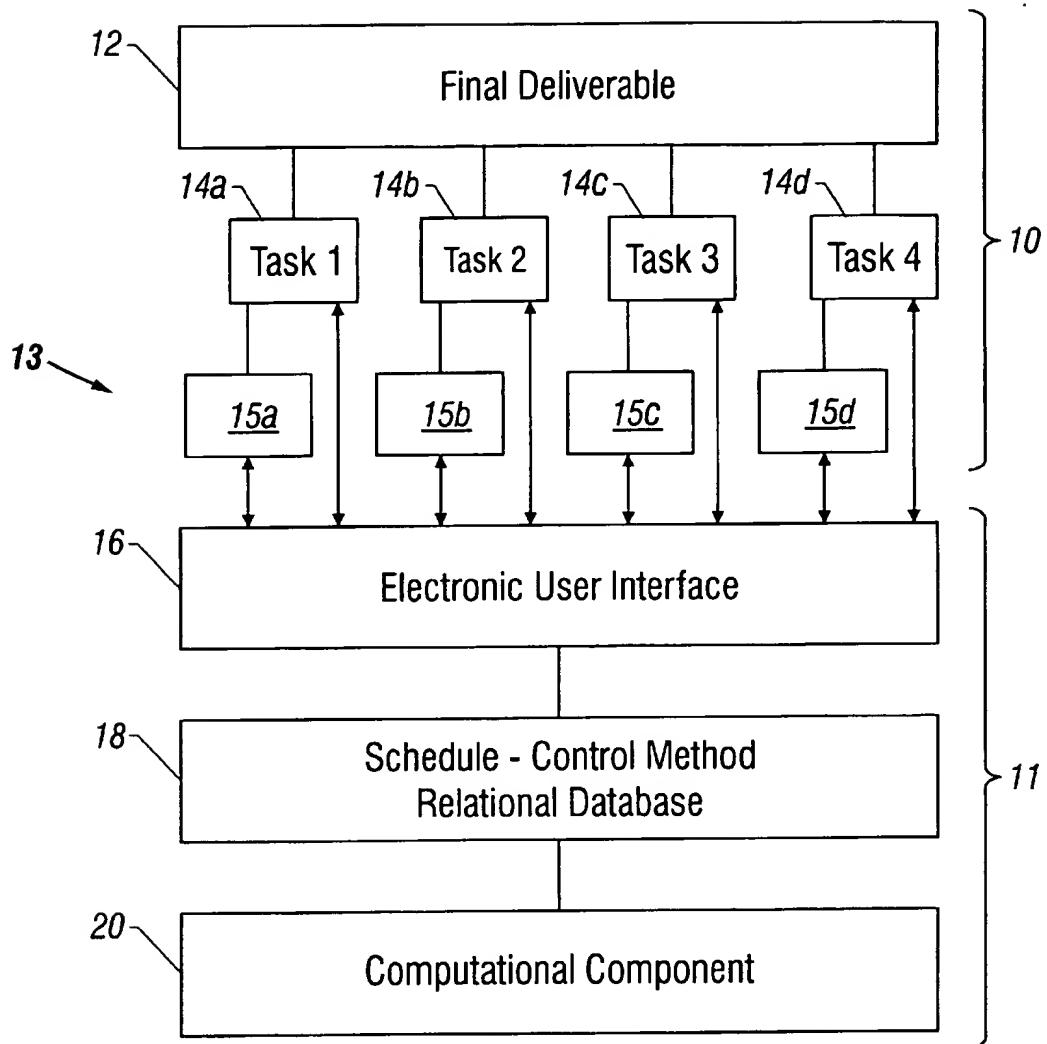
Attorney, Agent, or Firm—Fish &amp; Richardson P.C.

## [57] ABSTRACT

An schedule-control method for managing and controlling projects is described. The method is implemented on components including an electronic user interface, relational database, and computational component. These components are designed to process input data in a well-defined format called a receivable/deliverable (rec/del) format. Using this format, the project is broken down into a series of smaller components or "tasks". Each task involves a contract between a supplier and a receiver, and results in the production of a "product". Suppliers and receivers can enter up-to-the-minute input data in the rec/del format concerning a particular product. Input data are entered through the electronic user interface which can be e-mail or a user-interface computer program. Data are entered into tables of the relational database in the rec/del format. The input data are then rapidly processed with the computational component to generate output data indicating the status of the project.

20 Claims, 9 Drawing Sheets



**FIG. 1**

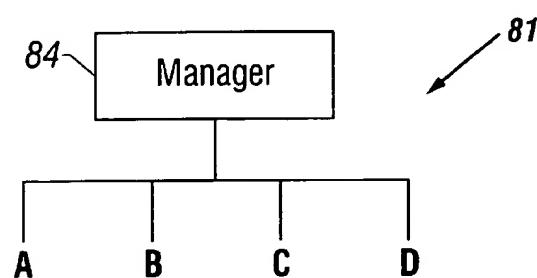
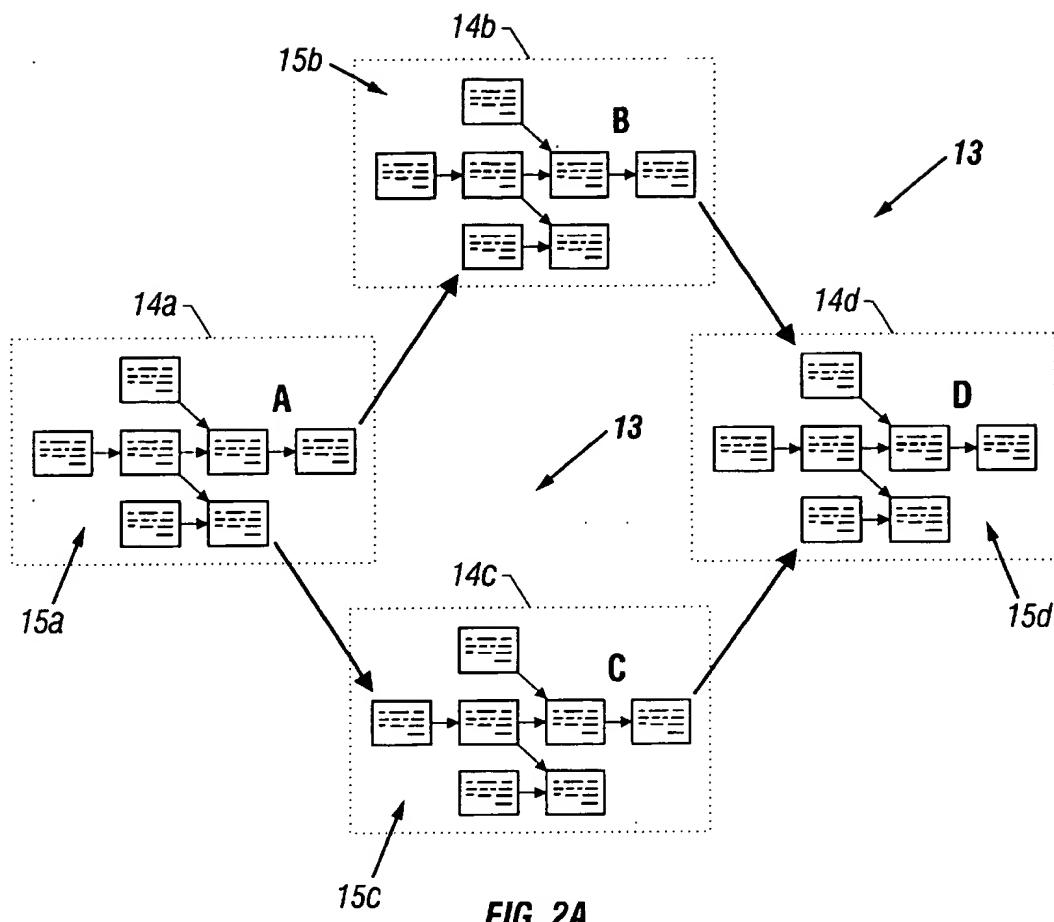


FIG. 2B

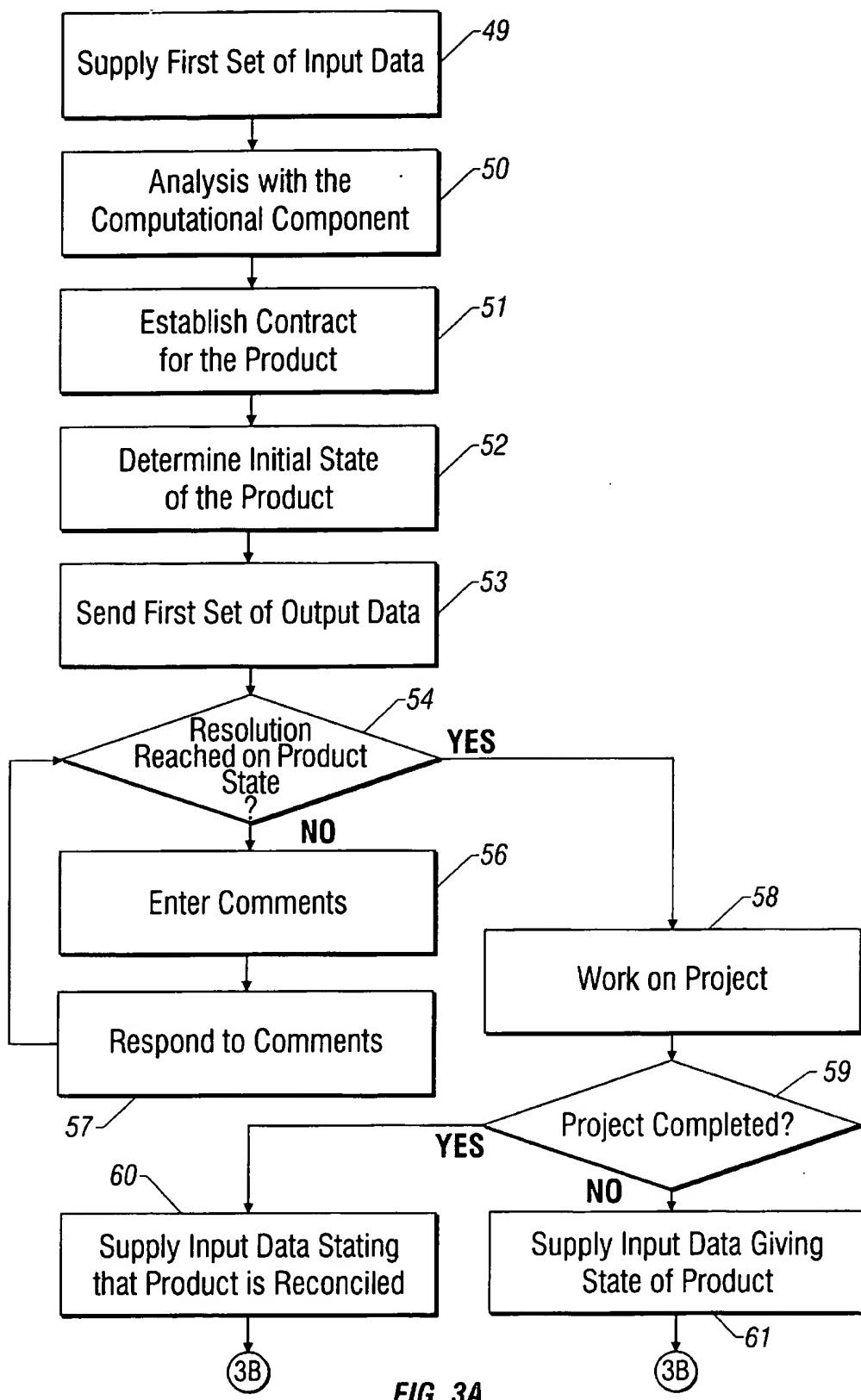
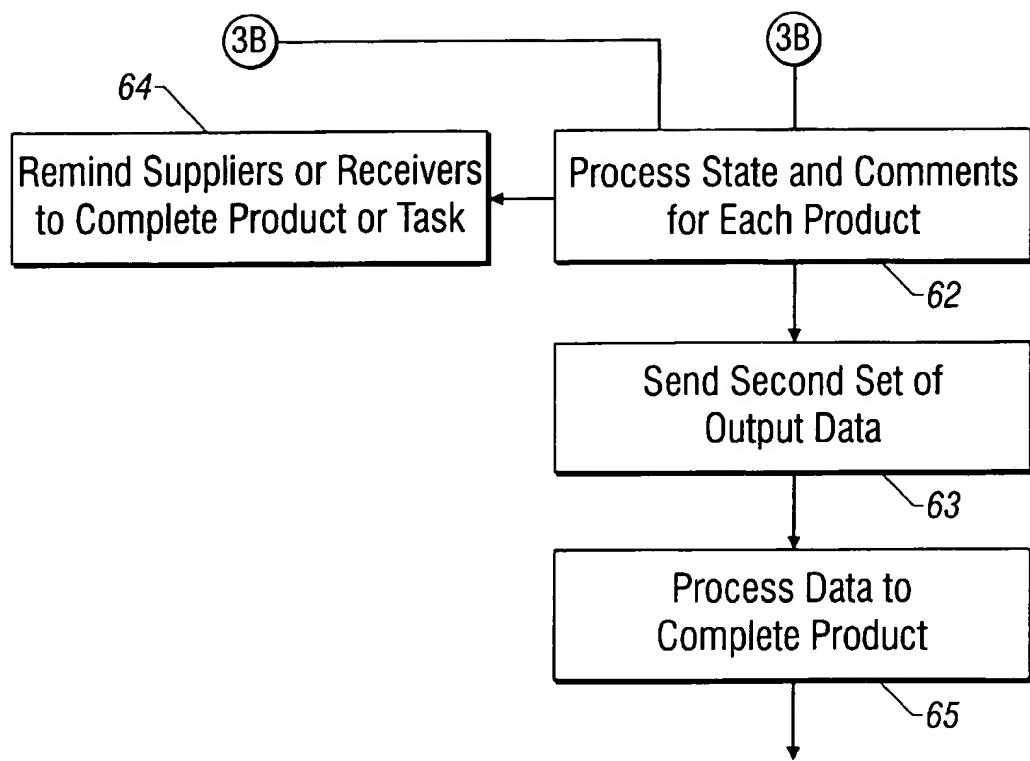


FIG. 3A



**FIG. 3B**

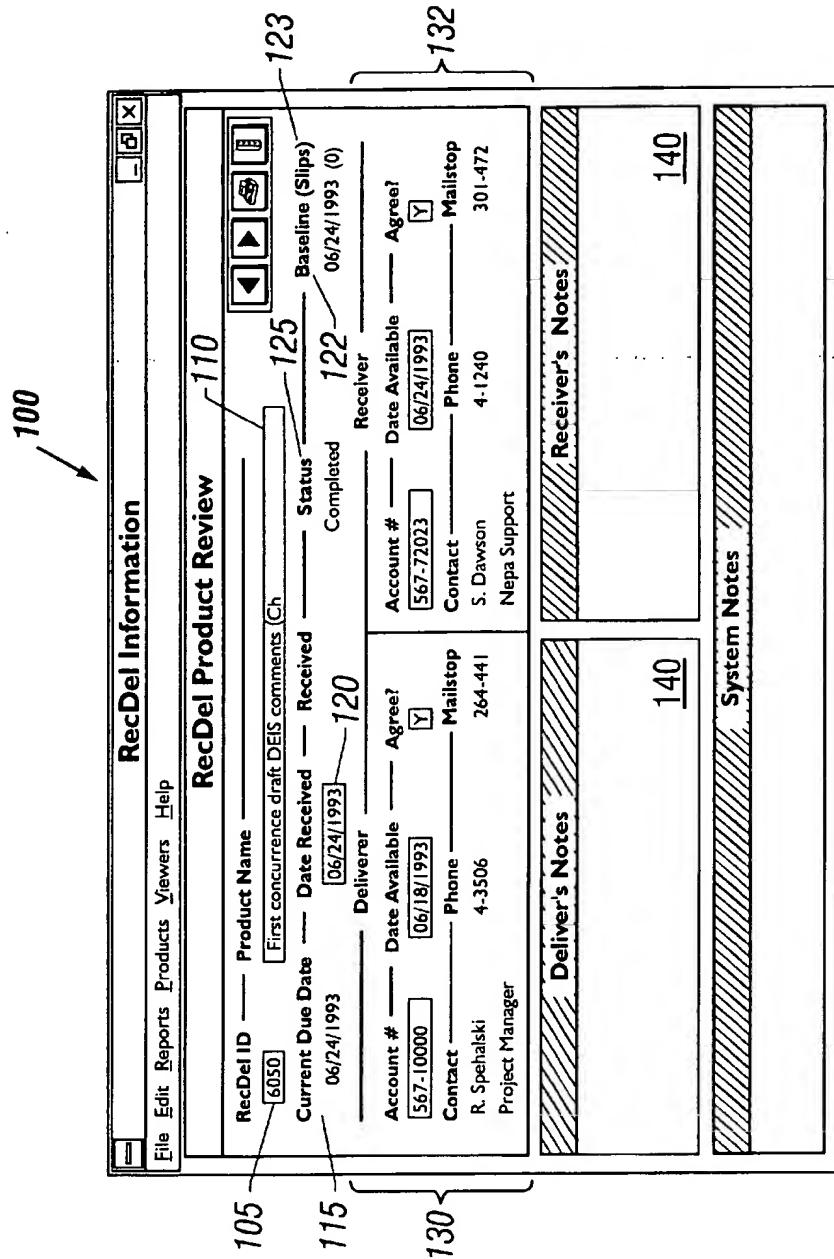


FIG. 4

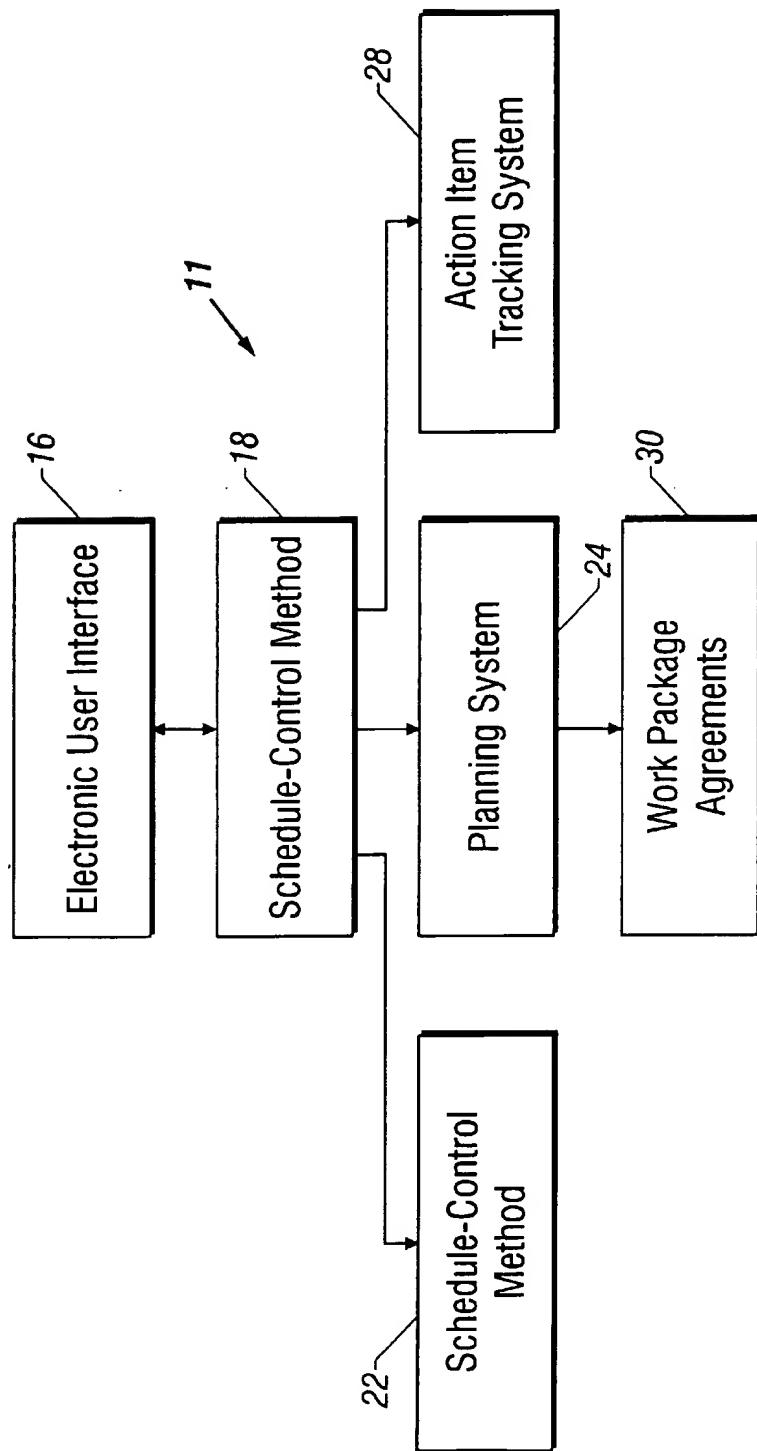


FIG. 5

70 → 74 → 76

72 →

**JPL CMIS Planning Tools**

**WORK PACKAGE AGREEMENT**

|      |      |      |                                                            |                                                                                                   |                   |                  |
|------|------|------|------------------------------------------------------------|---------------------------------------------------------------------------------------------------|-------------------|------------------|
| File | Edit | Help | Project Planning                                           | 2. DATE<br>[7/7]                                                                                  | 3. VERSION<br>[ ] | PAGE 1<br>OF [ ] |
|      |      |      | 4. WORK PACKAGE TITLE<br>Science Management Plan           | 5. ACCOUNT CODE<br>[567113AS-0-3110]                                                              |                   |                  |
|      |      |      | 6. WORK PACKAGE LEADER<br>Mary A. Johnson                  | 8. PROJECT/TASK/RTOP MGR<br>Mary A. Johnson                                                       |                   |                  |
|      |      |      | 9. WORK PACKAGE TITLE<br>Write the science management Plan | 78                                                                                                |                   |                  |
|      |      |      | 10. DESCRIPTION OF WORK PACKAGE RESPONSIBILITIES/APPROACH  | 80                                                                                                |                   |                  |
|      |      |      | 11. INPUTS/OUTPUTS                                         | <input type="checkbox"/> Exclude completed rec/dels <input type="checkbox"/> Exclude All rec/dels |                   |                  |

FIG. 6

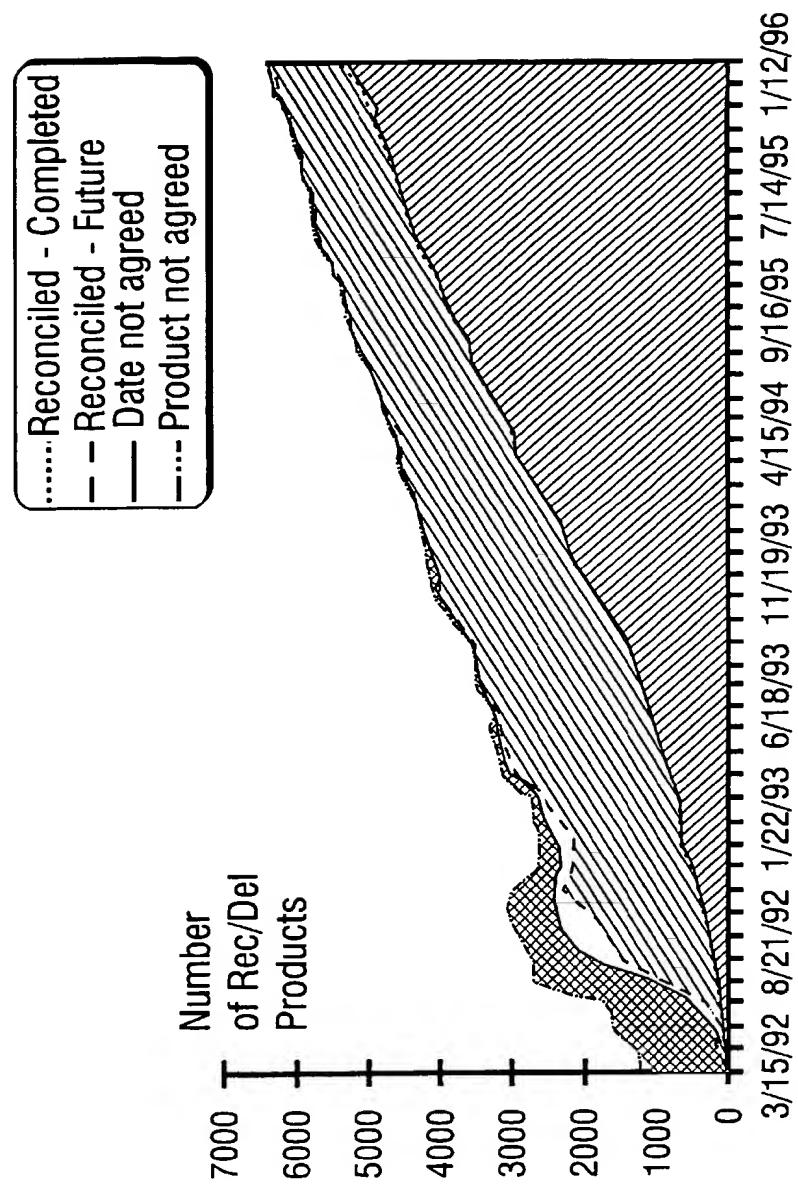


FIG. 7

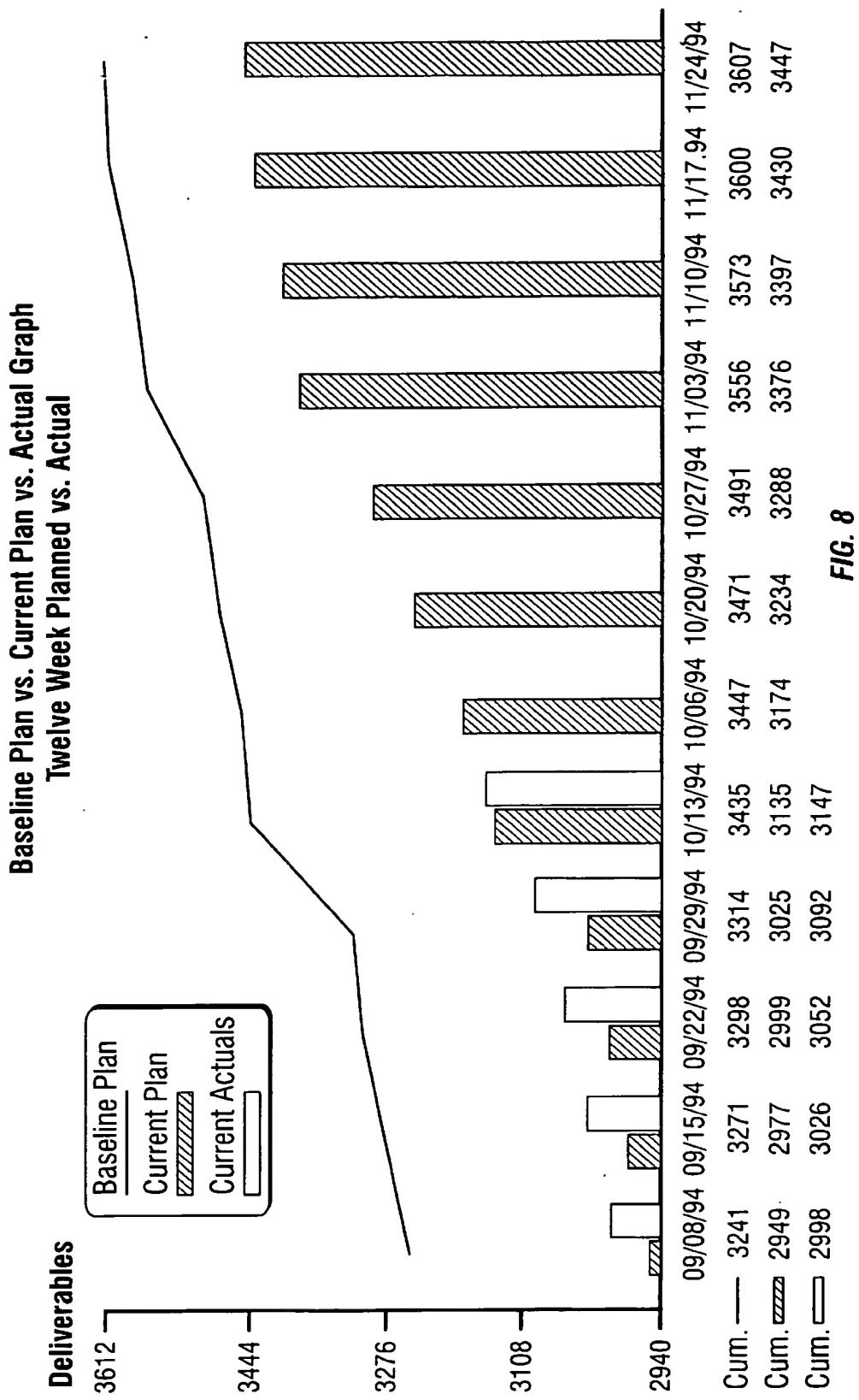


FIG. 8

**NETWORK BASED TASK MANAGEMENT****ORIGIN OF THE INVENTION**

The invention described herein was made in the performance of work under a NASA contract, and is subject to the provisions of Public Law 96-517 (35 U.S.C. §202) in which the contractor has elected to retain title.

**FIELD OF THE INVENTION**

This invention relates to techniques for automatically managing and controlling projects.

**BACKGROUND AND SUMMARY OF THE INVENTION**

Large, complex projects typically produce items such as designs, components, tests, and reports. These items are supplied by one party and received by another. Variables such as request dates, due dates, costs, and specifications are associated with each item. Each variable must be coordinated and scheduled between multiple sets of suppliers and receivers to prevent cost overruns and delays in the project's completion.

Both the variables in the project and the complexity of organizing these variables increase with the project's size. The project, in turn, becomes more difficult to manage.

Manufacturing projects for one-of-a-kind items (e.g., a NASA spacecraft) are particularly difficult to manage. These projects typically include larger numbers of supplied and received items than projects for manufacturing similar, well-established items (e.g., automobiles). A NASA spacecraft, for example, includes a large number of specialty parts which are not commercially available. These parts must therefore be fabricated in-house or sub-contracted to outside firms. Such parts often require specialized testing and detailed performance reports. This introduces more supplied and received items, and thus even more variables, into the project.

Control methods are implemented by manufacturing firms to organize and facilitate completion of the project. A standard control method features a hierarchy of managers (such as Project, Area, and Technical Managers), each of whom supervise a group of employees responsible for completion of a portion of the project. During day-to-day operations, individual employees supply, receive, and/or deliver particular items of the project; the status of each item then reported to the supervising manager. Information is then collected, tabulated, and evaluated to manage the project.

Several problems exist with conventional methods for project management. The inventor recognized that these methods lack a structured methodology for defining, recording, and processing the multiple variables that are associated with the project. Instead, information is typically communicated from employees to supervisors, and then through the management chain. Eventually, the information is somehow used to determine the project's status.

Standard project management requires the information to be communicated from one party to another. Good communication between suppliers and receivers is needed for efficient project management. The inventor recognized significant advantages from recording information directly in a centralized database. Otherwise, all employees cannot receive updated, real-time information about the status of the project. A lack of information can result in mis-communications between suppliers and receivers. These

factors become even more pronounced as the size and number of the project's variables are increased.

Applicants have developed a schedule-control method for managing and controlling projects to overcome these and other limitations. The method is implemented using an electronic user interface, relational database, and computational component. Each of these components work together to process input data in a special format that is defined herein as a "receivable/deliverable" (or "rec/del") format. Using the rec/del format, the method breaks down the project into a series of smaller components, referred to herein as "tasks". Each task involves a "contract" between a supplier and a receiver. The contract results in the production of a "product". Users can enter and access up-to-the-minute input data concerning a particular product or task from the rec/del system.

The schedule-control method includes several steps for receiving, processing, analyzing, computing and sending information for monitoring the status of the project. In a first step, suppliers or receivers enter the first set of input data to the method to identify the input and output products of their particular task. The first set of input data processed by the computer upon receipt are "bids". Bids are sent by suppliers and receivers over an electronic user interface and stored in the relational database of a computer.

The electronic user interface is either e-mail or a user-interface computer program. Both of these interfaces can be implemented on conventional personal computers connected and distributed over a local-area network (LAN) or over a wide-area network such as the internet. Each supplier and receiver must have access to a computer connected and distributed over the local-area or wide-area network. The combination of these features allows users to quickly and easily supply input data and access output data.

The input data within a bid identify a particular product by: 1) naming the product; 2) associating a receiver's identification number (i.e., an account identification code) with the product; 3) associating a supplier's identification number with the product; 4) associating the receiver's required delivery date with the product; and, 5) associating the supplier's available delivery date with the product. These input data are provided for each product in the project. A contract is formed when both the supplier and receiver agree to the criteria used to define the product.

The input data within the bid are then analyzed by the computational component to determine the "state" of each product in the project. For example, the states of a product include "reconciled", "date not agreed", "product not agreed", or "no impact". If one party changes one of the criteria during the course of the project, the product's state is no longer in agreement. This change must be reviewed and accepted by the other party to complete a new contract.

Each state includes different "comments" for describing the particular product. For example, a comment such as "completed" can be entered under the "reconciled" state; a comment such as "no deliverable" can be entered under the "product not agreed" state. The comments are sent as a first set of output data to the appropriate suppliers and receivers. These users can then negotiate and update the product's state by responding with new input data. For example, work performed or further negotiation may drive the product's state from "date not agreed" to "reconciled".

The negotiating process is repeated, and work on the contract is carried out, until the state is reconciled and the product is finished. The receiver ultimately determines when the product delivery date has been successfully completed.

The status of the entire project is determined by collectively processing the various states for each individual product or task. For instance, the states can be summed together. Once determined, the actual status of the project can be packaged as a second set of output data. Data are computed to generate real-time reports so that the status of the project can be determined at any particular time. These data can be accessed via the electronic user interface by the various suppliers and receivers involved with the project.

The second set of output data can be in the form of plots, charts (e. g. GANTT charts), and reports. These data can track a particular product or the entire project. In a preferred embodiment, the second set of output data is in the form of a plot comparing the project's actual status to its predicted status. Planning and performance reports serving as metrics for identifying problem areas can also be generated. Planning reports identify products where the delivery dates conflict with those requested by the receiver, the supplier is missing, or there is no receiver. Performance reports compare the actual and planned quantities of individual products over time.

All levels of the project's suppliers and receivers—ranging from high-level Project Managers to Technical Managers to Engineers—can use the schedule-control method to control and iterate their portion of the project. Users access a timely, robust set of processed data. Suppliers and receivers can predict future time periods which may require changes in the project's structure or adjustments in the deployment of the project's resources. Ultimately, the schedule-control method facilitates successful completion of the project.

The above-described techniques have many advantages when compared to conventional organizational methods. In particular, the rec/del format facilitates efficient communication between the suppliers and receivers of a particular product. Data are supplied and received by those directly involved with a particular area of the project. Input data in the rec/del format can be modified independently without modifying the schedule of the entire project.

Distributing the control of the project over a group of users is also advantageous. Individual users can focus more resources on monitoring and controlling the flow of products within the project. Less time is spent monitoring a single product and conveying and distributing data concerning the product to supervising managers.

Distribution of control also alleviates some of the responsibilities of the project manager. Personnel dedicated exclusively to planning the project are unnecessary, as each individual user has direct control over his or her plans. In effect, the schedule-control method becomes the project's centralized control center which simultaneously facilitates decentralized decision making. This decreases the probability of cost overruns, and increases the probability that the project will be completed according to plan.

The method is particularly effective when used with large, complex, one-of-a-kind projects. Such projects typically involve large numbers of interactions between suppliers and receivers, and consequently have large degrees of uncertainty in their schedules. For example, the method can be used to effectively manage projects such as the construction of a NASA spacecraft.

#### BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention will now be described in detail with reference to the accompanying drawings, wherein:

FIG. 1 is a block diagram which schematically shows a large project and the components of the schedule-control method of the invention;

FIGS. 2A and 2B are, respectively, a schematic drawing showing how the schedule-control method is used to manage the project of FIG. 1, and a managerial hierarchy for the project;

FIG. 3 is a flow chart showing the preferred steps used in the schedule-control method;

FIG. 4 is a printout of a computer screen used in the schedule-control method to provide input data in the preferred rec/del format;

FIG. 5 is a block diagram showing a project-management system using the schedule-control method of the invention;

FIG. 6 is a printout of a work package agreement (WPA) used in the schedule-control method;

FIG. 7 is a reconciliation chart for a large-scale project showing the status of the products comprised by the project; and,

FIG. 8 is a "planned versus actual" graph for the large-scale project of FIG. 7.

#### DETAILED DESCRIPTION

The schedule-control method according to the invention effectively manages and controls large-scale, complex projects. The method is implemented using an electronic user interface, relational database, and computational component. These features are designed to process input data organized in a preferred rec/del format. This format effectively separates the project into a series of smaller tasks, each of which involves a contract between a supplier and a receiver. Each contract relates in some way to the production of a product.

Suppliers and receivers using the schedule-control method provide bids featuring a first set of input data concerning their particular task. Input data are entered into the relational database via the electronic user interface. This data may not agree, e.g., the receiver's requested delivery date may not agree with the supplier's schedule. The bids may therefore be negotiated over the electronic user interface.

A contract is established once the two parties agree to the terms of the product. The computational component is then used to analyze the input data to generate a state for each product in the project. The states are then sent across the user interface to the appropriate suppliers and receivers as a first set of output data.

Suppliers and receivers negotiate the state of each product over the electronic user interface. Negotiations cause the product's state to evolve, and continue until the product's state is reconciled by both suppliers and receivers. The states of each product can be collectively processed at any time to determine the status of the project.

A second set of output data indicating the project's status is sent across the electronic user interface to both suppliers and receivers. These data can be conveyed through a number of different representations, including, but not limited to, charts, graphs, tabulated numbers, and/or reports.

Using this method, the various suppliers and receivers in the project are able to access an accurate and timely status of each task. All suppliers and receivers have access to a dynamic representation of the project's status. Moreover, control of the project is distributed over a group of users, as opposed to being allocated to a single management person or team. Ultimately, this facilitates efficient expenditures of

both time and monetary resources, and eventually successful completion of the project.

#### Components of the Schedule-control Method

FIG. 1 is a block diagram showing an exemplary project 10 to be managed and controlled using the components 11 of the schedule-control method according to the invention. The project 10 produces a final deliverable 12, such as a large scale NASA spacecraft.

The project 10 is broken down into a series of large-scale tasks 14a-14d. Each large-scale task is broken down into smaller tasks 15a-15d. Each task 14a-14d, 15a-15d results in a product. Products are designs, mechanical or electrical parts, tests, or reports. Each task is defined by a contract between at least two responsible parties, i.e., a receiver and supplier of the product.

Input data (indicated in the figure as the double-headed arrows 13) concerning the product of each task 14a-d, 15a-d in the project 10 are defined by the rec/del format. Either responsible party involved with the task can provide input data. Data are sent via an electronic user interface 16 to a schedule-control method relational database 18. The data stored in the database 18 are then analyzed with a computational component 20 to determine the contract and states for each product. The computational component 20 is a computer program written in a language which is compatible with the database 18.

Data are processed and analyzed with the computational component 20 to generate output data for the suppliers and receivers. Output data are stored in the relational database 18. These data are accessed via the electronic user interface 16 by the various suppliers and receivers involved with the project.

The electronic user interface 16, relational database 18, and computational component 20 are preferably installed on a system of computers, each connected and distributed over a LAN. Each computer on the LAN uses either e-mail or a user-interface computer program as the electronic user interface 16. E-mail is easily accessible, convenient, and available to a wide range of users. Moreover, e-mail is used to continuously supply new, up-to-date input data to the schedule-control method for processing and analysis.

FIGS. 2A and 2B are schematic drawings showing, respectively, a schematic drawing showing how the schedule-control method is used to manage the project 10 of FIG. 1, and a managerial hierarchy 81 for the project. For example, tasks 14a-d may involve science and project engineering, instrument development, ground system development, and spacecraft system development for a large-scale project such as manufacture of a NASA spacecraft. The large-scale tasks are managed by either Technical Manager A, B, C, or D.

Technical Managers A-D act as either suppliers, receivers, or both using the schedule-control method. In the shown example, Manager A supplies a product to both Manager B and Manager C. Both Managers B and C supply a product to Manager D. A contract defining the particular product to be delivered or received is established for each of these relationships using the schedule-control method. The status of each product is dynamic, evolving as scheduling events change or work is performed on the product. FIG. 2B shows a high-level Project Manager 84 monitoring the contracts between Technical Managers A-D.

Smaller tasks 15a-d exist within each of the larger tasks 14a-d. These smaller tasks are also managed with the rec/del system. Here, contracts for products are established between each of the employees (i. e., suppliers or receivers) under a Manager's control. The status of each product in the

project is negotiated and analyzed through the use of the electronic user interface, relational database, and computational component shown in FIG. 1. Each employee provides input data for their particular product and can receive status of the project at any given time. In this way, management of the project is distributed over and controlled by the project's entire work force, with each employee directly controlling his or her contract. This decreases the probability of cost overruns in the project, and increases the probability that the project will be completed according to plan.

#### Schedule-control Method

FIG. 3 shows a flowchart illustrating steps used in the schedule-control method 22. Each of the steps shown in the figure are carried out using the computational component. Input data in any appropriate rec/del format are supplied in bids by either the supplier or receiver. Data are supplied to the relational database of the system for analysis at step 49. The first set of input data identifies and defines the product. The definition of a product includes: 1) naming the product; 2) associating a receiver's identification number with the product; 3) associating a supplier's identification number with the product; 4) associating the receiver's required delivery date with the product; and, 5) associating the supplier's available delivery date with the product.

The first bid of input data is analyzed at step 50 by the computational component 20. A contract for the product is established at step 51 between the supplier and receiver only once criteria 1)-5), above, are agreed to by the supplier and receiver. The computer stores the bids of all receivers and suppliers, sorted by name. When another bid comes in, it is analyzed against the previously stored bid with that same name. Agreement of all terms yields a contract, and also establishes an initial state for the product at step 52. The initial state plus each iteration is sent by e-mail as a first set of output data to the appropriate suppliers and receivers at step 53.

One of four initial states are assigned to each product within the project. The allowable states include "reconciled", "date not agreed", "product not agreed", or "no impact". At this point the method determines if a resolution is reached on the product's state at step 54. If the "date not agreed" and "product not agreed" states result, it may be necessary to negotiate the state of the product by entering different comments which further describe the particular product (step 56). For example, a comment such as "no deliverable" can be entered under the "product not agreed" state. In this case, either the receiver or the supplier can respond to the comments by contacting the other party at step 57. This process is continued until the state of the product is resolved.

Input data are entered according to the following set of well-defined ground rules. To reduce e-mail "noise", and establish firm ownership of data relating to scheduling, suppliers and receivers only supply input data and receive output data for their particular task.

1. Only list receivables needed for delivery. Do not include comments on products or items such as schedules and implementation plans. Do not use the schedule-control method to build a documentation library or a document distribution list.
2. Lowest level of management attempts resolution. This rule recognizes that Technical Managers of the project have the responsibility and authority for deliveries in their respective area. Technical Managers have the responsibility to provide input data concerning receivables and deliverables at their level. Only if two Technical Managers cannot work out an agreement do higher levels of management get involved.

3. Negotiations between the supplier and receiver may be started by either party.
4. The supplier has the final say on the product name even if receiver provides the input data listing the name. If the receiver inputs a new product, the supplier may change the product description since that party makes the final decision on the product's name. Receivers need to be informed when this occurs.
5. Suppliers and receivers should provide any changes to their input data through the schedule-control method.
6. Any "slack" belongs to supplier. Slack is the time that a delivery is available before the required date. The supplier can use the slack to delay the product's delivery date (without being tardy) in order to deliver another product earlier.
7. The receiver can delete a low-level internal product without a supplier's approval. The receiver should contact the supplier and let that party know it is being deleted.
8. The receiver initiates the request for a deliverable. A deliverable must be required by a receiver in order to exist.
9. Only the receiver can decide when the when a product's delivery has been completed.

A list of the states and preferred comments for each state used during negotiation (steps 56 and 57) are defined in detail, below:

**Reconciled:** A product's existence has been agreed to and the planned delivery date supports the required date. The state is counted as fully reconciled. Comments for this state include: Completed, Dates OK, or Early OK.

**Date Not Agreed:** A product's existence has been agreed to, but the delivery date is not reconciled. Comments for this state include: Scheduled Late, Needs Both Dates, Needs Supplier Date, Needs Receiver Date, Supplier Slipped, or Receiver Needs Earlier.

**Product Not Agreed:** This is a product wherein the supplier and receiver do not agree on the product's existence. Comments for this state include: No Receivable, No Deliverable, Deleted by Supplier, or Deleted by Receiver.

**No Impact:** This is a product which both sides have agreed to delete and which remains on the report for one week as a check. The only comment for this state is: Deleted on Next Report. A no impact item is not counted in any statistics for the schedule-control method.

The meanings for each of the comments for the different states are described below:

#### RECONCILED STATE

| Comment   | Meaning                                                                                               |
|-----------|-------------------------------------------------------------------------------------------------------|
| Early OK  | The product is scheduled for early delivery.                                                          |
| Dates OK  | An agreement has been reached by both the receiver and supplier on the delivery date for the product. |
| completed | The product has been delivered.                                                                       |

#### DATE NOT AGREED STATE

| Comment          | Meaning                                                                         |
|------------------|---------------------------------------------------------------------------------|
| Needs Both Dates | The product is agreed to, but both receiver's and supplier's dates are missing. |

-continued

| Comment               | Meaning                                                                          |
|-----------------------|----------------------------------------------------------------------------------|
| Needs Receiver's Date | The product is agreed to, but the receiver's date is missing.                    |
| Needs Supplier's Date | The product is agreed to, but the supplier's available date is missing.          |
| Scheduled Late        | The product is agreed to, but is scheduled for delivery after the required date. |

|                        |                                                                                                                                               |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Supplier Slipped       | The product was reconciled. The supplier cannot make the original agreed-to delivery date, and has changed it to a later date.                |
| Receiver Needs Earlier | The product was reconciled. The receiver needs the product earlier than the originally agreed-to date, and has changed it to an earlier date. |

#### PRODUCT NOT AGREED STATE

| Comment             | Meaning                                                                                                                                                 |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| No Deliverable      | A receiver has requested a product, but the supplier hasn't identified that product in the deliverable list.                                            |
| No Receivable       | A supplier has specified a product in his or her deliverable list, but the receiver hasn't requested that product.                                      |
| Deleted by Receiver | A supplier has specified a product in his or her deliverable list, but the identified receiver doesn't need the product and has marked it for deletion. |
| Deleted by Supplier | A receiver has requested a product, but the identified supplier doesn't manufacture that product and has marked it for deletion.                        |

#### NO IMPACT STATE

|                        |                                                                                                                                                                                                                                                                                                                                                                                                    |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Deleted on Next Report | This product will be deleted from the next report because: 1) both the receiver and supplier have deleted the product; 2) the supplier originally submitted and has now deleted the product, and the receiver has never input data concerning the product; or, 3) the receiver originally submitted and has now deleted the product, and the supplier has never input data concerning the product. |
|------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

If an issue concerning the product is left unresolved, the opposing party then responds to the entered comments at step 57. In responding to the comments, the suppliers or receivers preferably take the following actions.

| Comment:       | Action:                                                                                                                                                                                                                                                                                                                                                                                                 |
|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| No Deliverable | <ol style="list-style-type: none"> <li>1. The supplier agrees to deliver the product with the current name to form an agreement.</li> <li>2. The supplier doesn't plan to deliver the product and notifies the receiver that the product is not planned to be delivered.</li> <li>3. The supplier agrees to deliver the product and reconciles a new name for the product with the receiver.</li> </ol> |
| No Receivable  | <ol style="list-style-type: none"> <li>1. The receiver accepts the product with the current name to form an agreement.</li> <li>2. The receiver doesn't need the product and notifies the supplier</li> </ol>                                                                                                                                                                                           |

-continued

| Comment:               | Action:                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Deleted by Receiver    | <p>that the product is not needed.</p> <ol style="list-style-type: none"> <li>3. The receiver agrees to accept the product and reconciles a new name for the product with the supplier.</li> <li>1. The supplier deletes the product to form an agreement.</li> <li>2. The supplier deletes product and contacts another receiver to accept delivery of the product.</li> <li>3. The supplier contacts the receiver to convince him or her that the product is needed.</li> </ol> |
| Deleted by Supplier    | <ol style="list-style-type: none"> <li>1. The receiver deletes product to form an agreement.</li> <li>2. The receiver deletes the product and contacts another source to deliver the product.</li> <li>3. The receiver contacts the supplier to convince him or her to provide the product.</li> </ol>                                                                                                                                                                            |
| Deleted on Next Report | <ol style="list-style-type: none"> <li>1. Do nothing; the product is removed from the database.</li> <li>2. If the user disagrees, he or she must notify the other party.</li> <li>3. If the product still exists but has the wrong supplier or receiver, the product is re-submitted with the correct supplier or receiver.</li> </ol>                                                                                                                                           |
| Needs Both Dates       | <ol style="list-style-type: none"> <li>1. The receiver inputs the required date.</li> <li>2. The supplier inputs the available date.</li> </ol>                                                                                                                                                                                                                                                                                                                                   |
| Needs Receiver Date    | <ol style="list-style-type: none"> <li>1. The receiver inputs the required date.</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                       |
| Needs Supplier Date    | <ol style="list-style-type: none"> <li>1. The supplier inputs the available date.</li> </ol>                                                                                                                                                                                                                                                                                                                                                                                      |
| Scheduled Late         | <ol style="list-style-type: none"> <li>1. The supplier can agree to deliver the product earlier; in this case, the new delivery date should be input.</li> <li>2. The receiver can agree to postpone the required date and inputs a new required date.</li> <li>3. The required date is slightly modified.</li> </ol>                                                                                                                                                             |
| Early OK               | <ol style="list-style-type: none"> <li>1. The product is reconciled; no action is required.</li> </ol>                                                                                                                                                                                                                                                                                                                                                                            |
| Dates OK               | <ol style="list-style-type: none"> <li>1. The product is reconciled; no action is required.</li> </ol>                                                                                                                                                                                                                                                                                                                                                                            |
| Supplier Slipped       | <ol style="list-style-type: none"> <li>1. The supplier finds a way to deliver the product on the original date.</li> <li>2. The receiver agrees to postpone the required date.</li> <li>3. A meeting is scheduled with the System Manager to resolve the problem.</li> </ol>                                                                                                                                                                                                      |
| Receiver Needs Earlier | <ol style="list-style-type: none"> <li>1. The supplier agrees to deliver the product earlier.</li> <li>2. The receiver finds a way to receive the product on the original date.</li> <li>3. A meeting is scheduled with the System Manager to resolve the problem.</li> </ol>                                                                                                                                                                                                     |

Dialog between the two parties continues until a resolution is reached at step 54. At this point, work is performed on the product by the supplier at step 58. The supplier and receiver then determine if the product is reconciled as a result of this work (step 59). If the product is completed, input data are supplied to the method stating that the product is reconciled at step 60. If the product is not completed, the appropriate state is input to the method at step 61. This state is updated in real-time.

The state and comments for each task included in the project can be processed by the computational component to

determine the status of the project at any particular time (step 62). The status of the project can be sent at any time to each supplier and receiver in the project. The status is preferably sent in the form of a second set of output data at step 63. In this way, the users involved with the project have real-time access to the project's status.

The second set of output data can take any of a number of forms, such as reports, graph and charts, GANTT charts, product listings, or metric reports. The output data can indicate a project history which is maintained by a comparison between the current and previous states of the various products of the project. Output data are preferably sent electronically over the electronic user interface. Alternatively, output data can be printed on paper and distributed to suppliers and receivers.

15 The suppliers and receivers also generate reports which show all of a project's unreconciled receivables and deliverables. Such reports also identify receivables and deliverables which were previously in agreement, but which have been subsequently broken by the receiver or supplier changing an available or required date. A new product is then reconciled by the other side indicating an agreement and providing an available or required date through the schedule-control method. The suppliers and receivers generate new reports which identify both the remaining unreconciled receivable/deliverable products and broken agreements. The negotiating process repeats itself until all of a supplier's or receiver's products are reconciled.

Reminders can also be sent over the electronic user interface at step 64. The reminders provide a mechanism 30 for suppliers and receivers to complete their particular product or task. In particular, the computational component is programmed to automatically send e-mails through the user interface to the responsible parties. These e-mails serve to update both suppliers and receivers on the status of the product. If there is an issue which needs to be resolved between the responsible parties, the method receives and stores information concerning the issue. The issue can also be supplied via an e-mail to a manager who, in turn, presents a resolution to the issue.

40 The output data are processed by the suppliers and receivers at step 65 to facilitate completion of each product in the project.

A number of additional steps may be performed before input data are entered into the schedule-control method 22. 45 For example, Technical Managers may provide pre-processing of the product by negotiating a product's status among themselves. If no reconciliation results and the Technical Managers are within the same division, the division representative may become involved in the process. 50 Otherwise, the appropriate System Manager gets involved. Ideally, negotiations continue until agreement is reached. However, input data may be entered into the schedule-control method before this point.

FIG. 4 shows a printout of a computer screen 100 used 55 with the schedule-control method to provide input data in the preferred rec/del format. Bids containing input data are entered directly into the screen 100 and then sent to the computational component for processing. Data such as the product's rec/del identification number 105, the product name 110, and the product's due date 115 and received date 120 are provided. The computational component processes the due date 115 and received date 120, returning a "baseline" 122. The baseline is the original agreed-to delivery date for the product. A "slip" 123 is indicated when this date 60 is not met. The screen 100 also lists information (e. g., contact names, mailing addresses, and phone numbers) concerning the supplier 130 and receiver 132 of the product. 65

Both the supplier and receiver of the product provide appropriate input data using the same screen 100. The input data are processed as described above to determine the status 125 of the project, which is then returned to the screen 100. Both the supplier and receiver can also enter comments 140 used, as described above, during negotiation of the product's state.

#### Project-Management System

FIG. 5 shows a block diagram listing the components 11 used to implement the schedule-control method 22. The components 11 include a computational component 20, a schedule-control system database 18, and an electronic user interface 16. In this case, the computational component 20 includes functions for performing the steps of the schedule-control method 22 shown in FIG. 3, along with functions for a planning system 24 and an action item tracking system 28 (AITS). Each of these systems performs a computational function, described below, which acts on a table of input data in the schedule-control method relational database 18.

Users can interactively modify, update, and categorize the state of receivables and deliverables for each product of a particular project using the schedule-control method 22. Input data are entered into the database 18 in the rec/del format using the electronic user interface 16; communication between suppliers and receivers proceeds according to a well-defined set of ground rules. Reconciliation of a product's existence and its required receivable dates and planned deliverable dates is achieved by a series of negotiations between the project's Technical Managers, Division Representatives, and System Managers at the appropriate levels. The state of each product is updated as work is performed on that product.

The planning system 24 is used in combination with the schedule-control method 22 to coordinate working agreements between suppliers and receivers. The planning system 24 additionally includes applications for work package agreements 70 (WPAs), an example of which is shown in FIG. 6. This form is completed by all Technical Managers before working on a task. Empowered users create, view, edit, and print WPAs 70 using the WPAs 30 system. Each WPA 70 documents the task by including its title 72, date 74, users who perform the work 76, the objectives of the task 78, and a description of the approach used to work on the task 80. WPAs can also include the task's duration, financial data, items that must be delivered for the work package to proceed, and start and projected completion dates for the activities described in the work package.

Users can initiate, edit, and print reports for action items and requests for action using the AITS system 28. Action items are the result of reviews and other technical meetings. They are items considered important enough to track and close formally. Requests for action are prepared during formal project reviews and are formally accepted, rejected, or adjudicated by the project's management. If the management accepts a request for action, one or more action items may be assigned. Input data for the AITS system includes the action item's or request for action's origin, assignor, date assigned, date completed or date due, and description.

Each of the components included in the computational component of the schedule-control method 22 is preferably programmed into a computer connected and distributed on a LAN. Like the schedule-control method, the systems are designed to access tables of data from the relational database 18.

The systems are preferably coded in programming languages, such as Foxpro™ (manufactured by Microsoft, Corp., One Microsoft Way, Redmond, Wash. 98052-6399)

which can easily process data from the relational databases. Most preferably, the systems are coded into personal computers running conventional platforms, such as Windows™ or Apple Macintosh™ platforms. Any conventional relational database software can be used for this application.

The computers running the schedule-control method are preferably connected and distributed on a LAN and interfaced with a printer. Any standard LAN software package, such as the Netware™ package manufactured by Novell, Inc. (122 East 1700 South, Provo, Utah. 84606-6194), can be used to connect the system of computers.

Preferably, the computers include software for running conventional e-mail applications. Any standard e-mail software package, such as the cc:Mail™ package manufactured by Lotus Development Corp. (55 Cambridge Parkway, Cambridge, Mass. 02142-1295), can be used for this application.

The schedule-control system is preferably programmed in a Windows™ or Apple Macintosh™ platform. The schedule-control system is preferably programmed so that each of its features is represented as an icon or a pull-down menu (see, for example, FIGS. 4 and 6). Users can thus "point and click" using an external mouse, thereby simplifying and expediting operation. Input data can be edited using standard "undo", "copy", "cut", and "paste" commands available in commercially available windows-based software.

#### Application of the Schedule-control Method to the Cassini Project

The schedule-control method, described herein in its preferred embodiment, is used to manage the Cassini project, a space mission to Saturn under development at NASA's Jet Propulsion Laboratory (JPL). The project encompassed more than 1,000 employees and had an annual budget in excess of \$200 million. Employees (i.e., suppliers and receivers) involved in the project use the schedule-control method following the guidelines described above. Input data provided by the employees are used to generate a series of graphical output data, such as reconciliation charts and planned versus actual graphs for the project.

FIG. 7 shows a reconciliation chart plotting the status of all receivable and deliverable products for the project as a function of time. The plot is generated in response to input data provided by individual suppliers and receivers for the project. The output data in the plot are broken down into four categories using the schedule-control system. The definitions of the states are entitled "reconciled", "date not agreed", and "product not agreed", and the "broken agreements" according to the categories given above. Typically, a reconciliation plot such as that shown in FIG. 7 will be distributed on a monthly basis to the Project Managers, Division Representatives, and System Managers of the Cassini project. Inspection of the plot by these personnel is used to determine the status of the project.

The number of unresolved products in the project (i.e., those having the "date not agreed", "broken agreement", or "product not agreed" status) was relatively high in the beginning stages. One year later, these unresolved products were nearly eliminated. In fact, since implementation of the schedule-control system, 99.9% of the project's delivery plans have been reconciled.

FIG. 8 shows a "planned versus actual" graph plotting the status of a series of products over a twelve-week period of the Cassini project. The light bars in the graph represent the "current plan" as determined by the input data from various suppliers and receivers using the rec/del format. The current plan is the most recent agreed-to delivery date for the

products in the project. The total number of counts for these bars represents the cumulative number of products scheduled to be finished by the status date according to the current plan. The dark bars represent the actual completed products as determined from the input data. Here, the total number of counts represents the cumulative number of rec/del products that were actually finished on or before the status date listed on the horizontal axis. These values can be compared to a cumulative "baseline plan" which is the original agreed-to delivery date for the products. These data, in turn, can be processed to facilitate successful completion of the project. For example, steeply sloped curves in the data typically indicate unrealistic plans or critical products being delivered to many different receivers.

Data from the graph was generated by the computational component of the schedule-control system using input data provided by the suppliers and receivers involved in the project. The period over which the planned versus actual status of the project is calculated can be adjusted. Typically, graphs similar to that shown in FIG. 8 covered adjustable periods ranging from 12 weeks to 1 year. As is evident from the data, all parties involved can determine the cumulative status of the project as a function of time.

Other embodiments are within the scope of the invention. For example, this system has been described as being carried out in software. It can be alternately carried out using hardware techniques where dedicated modules are used to carry out each function that has been described above. Likewise, any step described above can be replaced with one or more steps, or can be removed, to perform the schedule-control method. Alternate steps can be used to form contracts for each task and monitor the status of each product in the project. Similarly, the state, status, and comments for each product can be different from those described above.

Still other embodiments are within the scope of the following claims.

What is claimed is:

1. A method for schedule-control planning of a project separated into multiple tasks, each of which generates an independent product supplied by a supplier and received by a receiver, said method executed in a computer system, said method comprising:

receiving a first set of input data for a task generated in the project from either a supplier or a receiver using an electronic user interface;

storing the first set of input data in a database;

analyzing the first set of input data for the task stored in the database with a computational component to generate a contract and a state for a product associated with the task; and,

processing the state of the product to facilitate planning of the project.

2. The method of claim 1, wherein said processing further includes negotiating the state of the product.

3. The method of claim 2, wherein said negotiating includes:

sending a first set of output data over the electronic user interface to the supplier, receiver, or supplier and receiver for the task; and

receiving a second set of input data in response to the first set of output data from either the supplier, receiver, or supplier and receiver for the task.

4. The method of claim 3, wherein said negotiating further includes repeating said sending and receiving until an agreement between the supplier and receiver is reached.

5. The method of claim 3, wherein the database is a relational database and the state of the product is updated during said negotiating by sending the updated state over the user interface and to the relational database.

6. The method of claim 1, wherein said processing further includes updating the state of at least one product after performing work on the product by sending the updated state over the user interface and to the database.

7. The method of claim 1, wherein the task is a first task, the method further comprises:

separating the project into multiple tasks, including the first task, associated with multiple products supplied by the supplier and received by the receiver; and

computing each state for each product to determine a status of the project.

8. The method of claim 7, wherein said processing of each state includes summing together each of the states.

9. The method of claim 7, wherein after said computing, said method further includes sending over the electronic user interface to the supplier, receiver, or supplier and receiver of each task a chart, plot, graph, or report describing a status of the project.

10. The method of claim 9, wherein the supplier, receiver, or supplier and receiver of at least one task sends further input data over the electronic user interface in response to the chart, plot, graph, or report.

11. The method of claim 1, wherein the input data for the task provided through the user interface includes:

a name for the product;

a receiver's required delivery date for the product; and, a supplier's available delivery date for the product.

12. The method of claim 11, wherein said processing further includes determining from the input data whether or not the supplier can supply the receiver with the product by the receiver's required delivery date.

13. The method of claim 12, wherein the state assigned to the product include a status of "reconciled", "date not agreed", "product not agreed", or "no impact".

14. The method of claim 1, wherein said receiving, processing, and analyzing are performed on a networked computer.

15. The method of claim 14, wherein the project comprises a plurality of tasks and wherein a computer is assigned to each supplier and receiver in the project.

16. The method of claim 15, wherein each computer is connected to one another and distributed over a local-area network.

17. The method of claim 1, wherein the electronic user interface is electronic mail.

18. The method of claim 1, wherein said processing is performed with computer code operating on a relational database.

19. The method of claim 18, wherein the computer code is written in the Foxpro™ programming language.

20. A software program for a project-managing system to control planning of a project that is separated into multiple tasks, comprising instructions for causing a computer to:

provide an electronic user interface so that a first set of input data for each task can be delivered by either a supplier or receiver;

receive the first set of input data for each task from either the supplier or receiver using the user interface;

store the first set of input data in a relational database;

analyze the input data for each task stored in the relational database with a computational component to generate a contract and an initial state for products provided by the project; and,

process the state of at least one of the products to facilitate planning of the project.

\* \* \* \* \*



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United States Patent [19]  
Fox

[11] Patent Number: 5,890,134  
[45] Date of Patent: Mar. 30, 1999

## [54] SCHEDULING OPTIMIZER

[75] Inventor: Barry Ross Fox, Houston, Tex.

[73] Assignee: McDonnell Douglas Corporation,  
Huntington Beach, Calif.

[21] Appl. No.: 602,966

[22] Filed: Feb. 16, 1996

[51] Int. Cl.<sup>6</sup> ..... G06F 17/60

[52] U.S. Cl. .... 705/9; 364/468.06

[58] Field of Search ..... 705/8, 9; 364/468.05-468.1;  
395/670-674, 557

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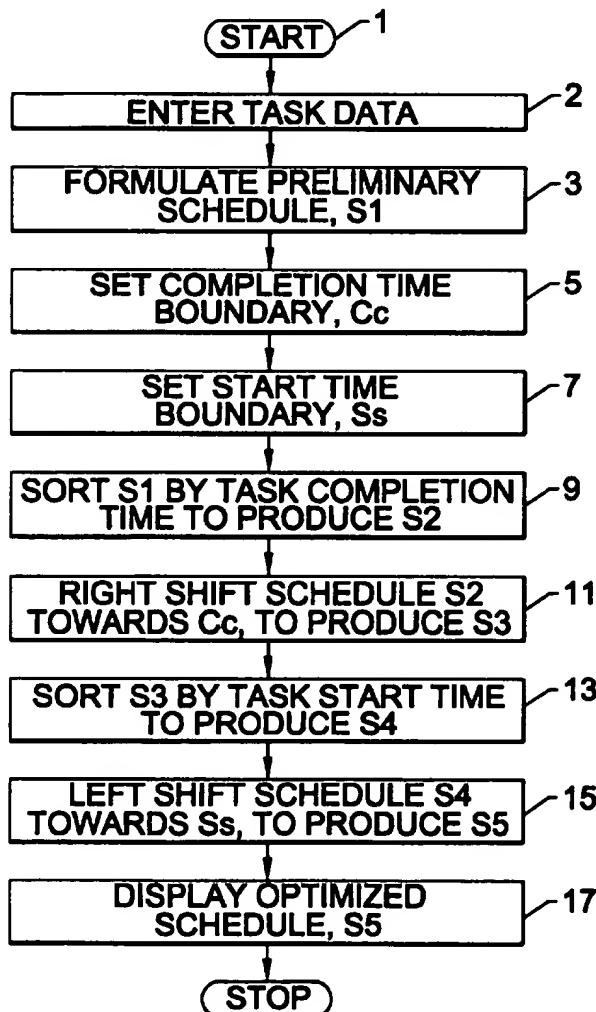
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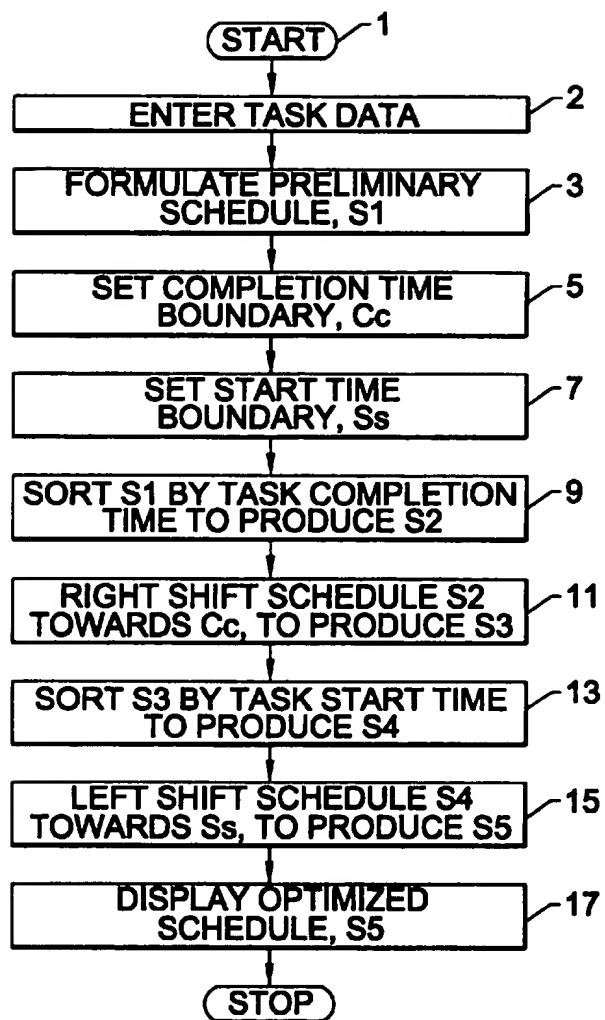
Primary Examiner—Frantzy Poinvil  
Attorney, Agent, or Firm—Alston & Bird LLP

## [57] ABSTRACT

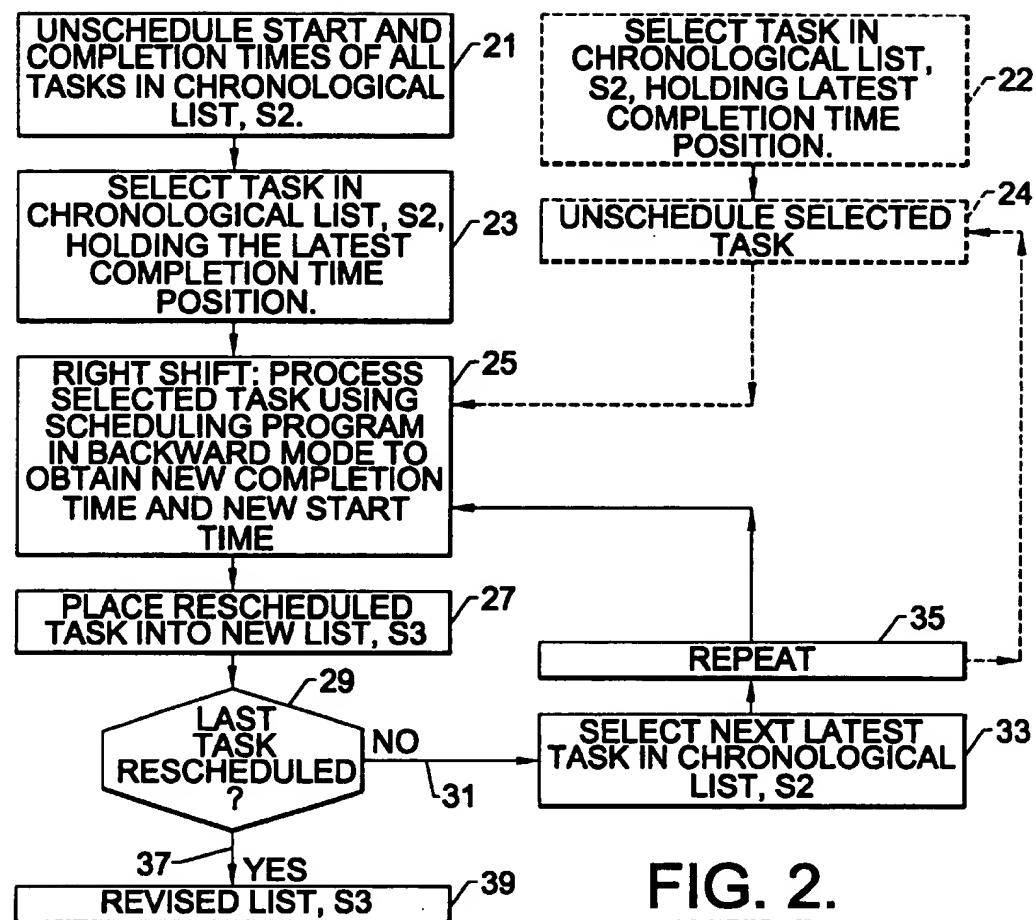
A schedule optimizing algorithm improves scheduling quality, reducing a schedules cycle time and requiring only marginal increase in computer execution time. Lower quality computerized scheduling programs are substantially improved through the additional steps of sequential left time shifting and right time shifting of respective chronologically sorted completion time and starting time task listings.

14 Claims, 3 Drawing Sheets





**FIG. 1.**

**FIG. 2.**

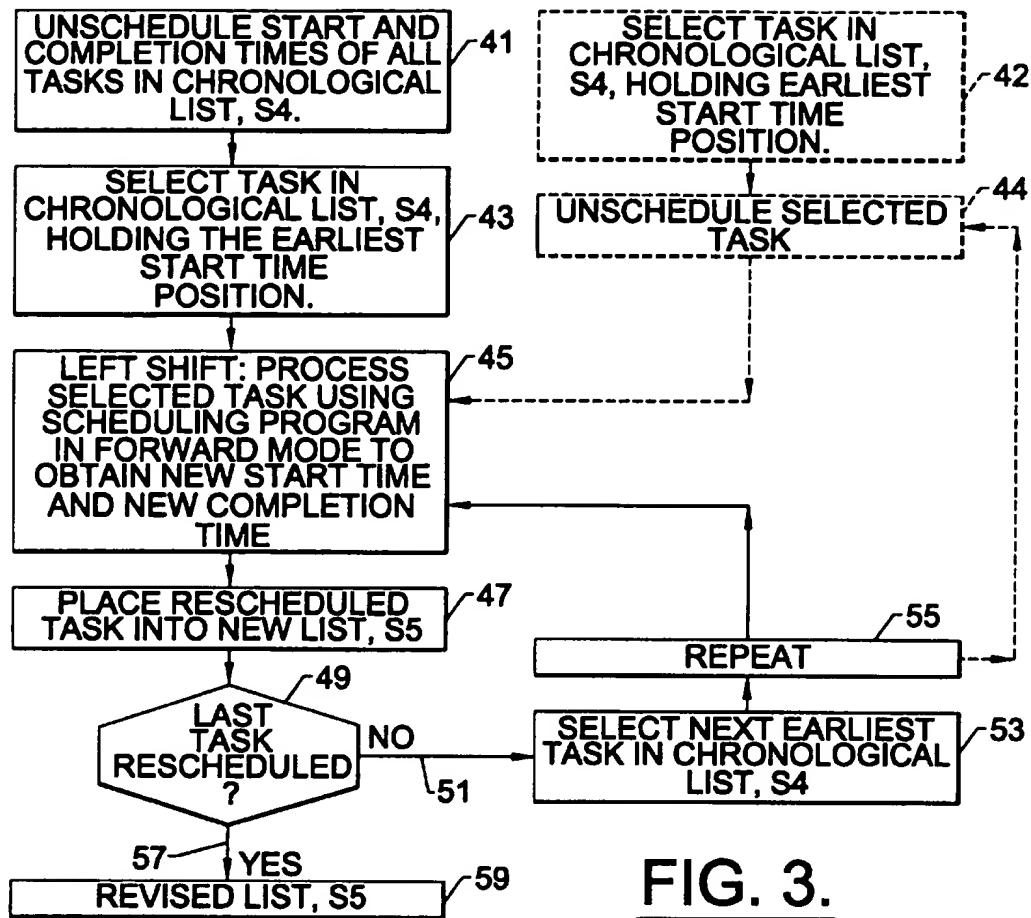


FIG. 3.

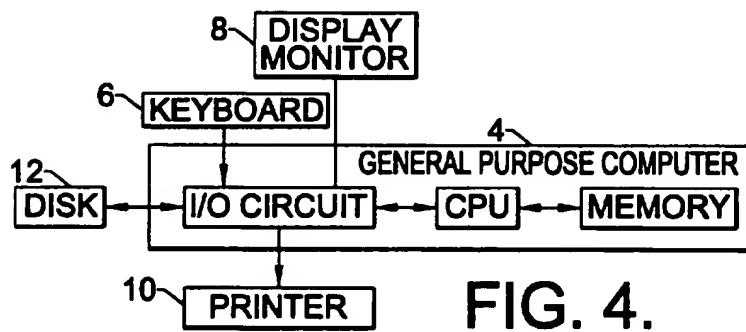


FIG. 4.

## SCHEDULING OPTIMIZER

### FIELD OF THE INVENTION

This invention relates to a computerized scheduler and, more particularly, to an improved method or algorithm for efficiently defining and/or optimizing the performance schedule of the multiple tasks necessary to the accomplishment of a project, particularly a manufacturing project, taking both resource and precedence constraints into account.

### BACKGROUND

It is well recognized that the construction of any building, machine or equipment, generally referred to as a project, requires the collective performance of a number of individual operations or tasks for successful completion. Resources are required, as example, personnel, trained to accomplish the task, capital equipment and other resources, supplies and component parts, which need to be procured or built. Each task requires a finite time, determined by past experience, for completion. And precedence must be followed, in that some tasks typically must be completed before other tasks in the project may begin.

Prudence requires planning and, particularly, formulation of a schedule that defines the who, when, where and the how that is necessary for completion of the project in an orderly and efficient manner. In earlier eras, the foreman or manufacturing engineer, possessed the experience, training and intellect to arrange the tasks required by the project in mind and specify which persons were to carry out the tasks, the resources and supplies required, and other necessary details. That person could also provide a reasonable estimate of the time of completion as allowed prediction of a delivery date.

As modern factory projects attained greater complexity, schedules required better definition and were more scientifically defined by persons, often now referred to as industrial engineers. With essentially pen, ink and calculator, such persons were able to search through the requirements and present the paper documents defining the tasks and the resources associated with them and to arrange the order of tasks for completion, creating time-lines of individual tasks and chronological order of the tasks commencement and completion, namely produce a project schedule. As projects became more complex still, those scheduling techniques often proved inefficient and, while less than perfect, necessarily sufficed until the advent of automated calculating machinery, such as the modern digital computer and the now familiar scheduling programs carried out by the computer.

In the modern competitive industrial world, however, all resources and personnel are held to a minimum and must be allocated. Little excess personnel or equipment is available to a manufacturer. Excess resources are expensive to maintain and, if carried idle by the manufacturer for too long, results ultimately in financial collapse attributed to inefficiency. Thus, the usefulness of a schedule as a useful industrial tool and the benefit of efficient scheduling to industrial craft is well understood.

In this endeavor the modern digital computer, more specifically, a programmed general purpose digital computer, plays an important role as a scheduler to expedite production of an acceptable schedule definition more quickly and efficiently than could be accomplished by human intellect alone. The computer is governed by a program, called software, and makes the necessary steps, called algorithms, set forth by the program. And those programs of interest here are those that deal with scheduling,

hereinafter referred to as scheduling programs. In and of itself the digital computer is an instrument or tool for specifying not only the steps of the desired schedule, but also carries out the steps or method for attaining and defining those steps.

One known scheduling program used in the industry is called COMPASS, which is written in the well known ADA computer language or source code, as variously termed, and is used principally with workstation computers using the Unix operating system. A more recently introduced scheduling program is Microsoft Project which is written for operation on personal type computers, such as the Intel 486 and 586 processor based personal IBM type computers with Windows operating systems.

Scheduling is a difficult art. Mathematically the scheduling process is categorized as N.P.-Hard. This means that in order to determine an optimum schedule, one that accomplishes the project with available resources in a minimum amount of time to project completion, and which can be mathematically proven to be the optimum schedule, requires an unduly large amount of searching operations by the computer. That in turn requires computer time in such large amounts as to render those kinds of computerized scheduling programs impractical for industrial use.

To construct a modern aircraft involves many thousands of individual tasks, a vast number of technicians and assemblers, and a large amount of resources. To prepare a schedule for such a project would likely overwhelm the genius of any person working with pen, paper and calculator and would require an inordinate amount of time for one person or even a group of people to schedule to complete with minimal errors. One should not expect that the definition of a schedule to construct an aircraft should require preparation time that exceeds the construction time of an aircraft, disregarding the realism which necessitates redefining the schedule when tasks are not completed on time as originally planned, as for example due to acts of force majeure, such as electrical failure or flood.

As a consequence the scheduling programs implemented for industry are referred to as "Heuristic" in nature. That is, the algorithm that forms the essence of the scheduling program is based on a skilled person's intuition. Based on experience such programs are known to function to produce a good schedule, and/or improve an existing schedule. The logic as to why, the mathematical proof, however, is absent. The present invention is also heuristic in nature and the new algorithms presented are also based on intuition.

The duration between the start of the first scheduled project and the finish of the last scheduled task in a multiple task project is one measure of schedule "quality", often referred to as span time or cycle time. Another is the time required for the time to complete the process of formulating a schedule, that is, for the computer to execute the algorithms and process the entered task data to generate and display the schedule, often referred to as the "execution time".

Even Heuristic based scheduling programs are not created equal and vary widely in quality. Most computer assisted programs for producing good schedules suffer one of two basic flaws. Either they use simple methods that work quickly, but produce schedules with inferior "cycle time", or that use methods that produce schedules with good cycle time, but require excessive amounts of computer execution time. In short, the schedules produced takes too much time for project completion or the program takes too much time to formulate the schedule.

Some of these scheduling programs, such as one attributed to Gil Syswerda, provide an improved schedule, each time the program is run, continuing until a point of diminishing return is reached at which additional improvement to the schedule is minuscule and does not justify further investment of computer execution time. The algorithm produces incremental improvement. The present algorithm is of like kind, producing incremental improvement each time the algorithm is applied to the most recently produced schedule.

An object of the present invention is to provide an improved scheduling method and apparatus and to improve upon existing scheduling methods and apparatus.

Another object of the invention is to provide an algorithm that may be added to existing scheduling programs for improving the quality of the formulated schedules.

An additional object of my invention is to provide an efficient method for defining a high quality schedule.

Still another object of the invention is to produce schedules for projects comprised of multiple tasks having minimal cycle time with only marginal increase in computer execution time.

And an ancillary object of the invention is to provide a novel scheduling algorithm that enhances existing scheduling programs.

#### SUMMARY OF THE INVENTION

In accordance with the foregoing objects, a new scheduling algorithm is presented that improves the quality of existing computer assisted scheduling programs and as integrated therein defines an improved scheduling program.

In the improved method, a multiple task schedule, initially formulated by the scheduling program, is subjected to the additional processing steps of: setting a completion time boundary that is as late or later than the latest completion time of any of the tasks; setting a start time boundary that is no later than the earliest start time of any of those tasks; preparing a chronological listing by completion time for the tasks, a sort, whereby the tasks are assembled in a different order than before; starting with the task having the latest completion time and continuing through the chronological listing in reverse chronological completion time order, "right shifting" each task in time, that is rescheduling each task in the chronological listing to a new completion time that is no later than and as close to the completion boundary time as is permissible without violation of any resource constraint, to create a first revised temporary listing of tasks arranged in the same order found in the chronological listing; preparing a second chronological listing by start time for each task in the revised listing, another sort; and, starting with the task in the second chronological listing having the earliest start time and continuing in chronological order through the remaining tasks, rescheduling each task to a new start time that is no earlier than and as close to said commencement time boundary as is permissible without violation of any resource constraint, whereby each task is again assigned new start and completion times, but remain arranged in the same order found in said second chronological listing, to thereby formulate the improved or optimized schedule.

As empirical evidence demonstrates the foregoing algorithm produces a schedule that prescribes a reduced cycle time for a project. That reduced cycle time translates to increased efficiency and cost savings, as those skilled in the art recognize.

It is appreciated that the foregoing algorithm can be used to either build efficient schedules in the first instance or to improve upon a given schedule.

A further aspect of the invention includes programming elements for electronic digital computers. Such programming elements include media, such as magnetic disks, optical disks and the like. The programming elements according to the present invention have program data encoded thereon for activating an electronic digital computer to perform the previously described method.

#### BRIEF DESCRIPTION OF THE DRAWINGS

##### 10 In the Drawings:

FIG. 1 is a flow chart illustrating the steps and operations defining a preferred embodiment of a scheduling program that incorporates the novel steps or algorithm characterizing the invention;

15 FIG. 2 is a flow chart of a right shift subroutine used in the method of FIG. 1;

FIG. 3 is a flow chart of the left shift subroutine used in the method of FIG. 1; and

20 FIG. 4 illustrates a computer and associated peripheral accessories with which to carry out the scheduling program.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference is made to the flow chart of FIG. 1 which illustrates the method defining the optimized scheduling program that is carried out by a digital computer. Brief reference may be made also to the accompanying flow charts of FIGS. 2 and 3, which illustrate in greater detail certain steps comprising the right shift and the left shift subroutines or operations generally illustrated in FIG. 1.

As becomes apparent, the detailed description that follows is presented largely in terms of algorithms and symbolic representations of operations on the data bits and data structures found within a computer memory. These algorithmic descriptions and representations are a convenient means used by those skilled in the computer programming arts to effectively convey the substance of their work to others.

An algorithm is here, and generally, is conceived to be a self-consistent sequence of steps leading to a desired result. 40 These steps are those requiring physical manipulation of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It proves convenient at times, principally for reasons of common usage, to refer to these signals sometimes as bit patterns, values, elements, symbols, characters, data packages, or the like. It should be borne in mind, however, that all of these and similar terms as may appear herein are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities.

Further, the manipulations performed are often referred to in terms, such as sorting or comparing or inspecting data 45 such as times, that are commonly associated with mental operations performed by a human operator. No such capability of a human operator is necessary, or desirable in most cases, in any of the operations described herein that form part of the present invention; the operations are machine operations. Useful machines for performing the operations of the present invention include general purpose digital computers or other similar devices. In all cases there should be borne in mind the distinction between the method of operations in operating a computer and the method of computation itself.

The present invention also relates to an apparatus for performing these operations. This apparatus may be spe-

cially constructed for the required purposes, or it may comprise a general purpose computer as selectively activated or reconfigured by a computer program stored in the computer.

The method of the present invention may be practiced on any conventional digital computing apparatus such as diagrammatically illustrated in FIG. 4. There, the scheduling program illustrated by the flowchart of FIG. 1 is stored for execution in a computer 4, e.g. such as an IBM PC/AT type 586 personal computer. The data inputs described herein may be entered into the computer through an associated keyboard device 6. The scheduling program may be stored initially on a floppy disk, the programming element, and loaded into the computer via a peripheral device, such as a floppy disk drive 12. The final, conflict free schedule would preferably be displayed on a graphics display device 8 such as a computer monitor and/or printed out on a printer 10. The scheduling program embodying the novel algorithm would preferably be written in a conventional programming language such as "ADA". The program has, however, been successfully implemented on a Sparc workstation computer, manufactured by Sun Microsystems of Sunnyvale, Calif., among others.

The algorithms presented herein are not inherently related to any particular computer or other apparatus. In particular, various general purpose machines may be used with programs written in accordance with the teachings herein, or it may prove more convenient to construct a more specialized apparatus to perform the required method steps. The required structure for a variety of these machines will appear from the description given below.

The present improvement is described as an addition to a pre-existing scheduling program, such as the COMPASS scheduling program referred to earlier, as example. The COMPASS program meets certain minimum requirements: First, the scheduling program contains the capability of allowing one to sort scheduled tasks by start time and also by finish time. Second, such program contains the ability to construct schedules forward in time, beginning with a designated start time, as example a start time designated by the program user, often referred to as a "forward mode", and backward in time, beginning at a designated finish time, referred to as a "backward mode". And thirdly, the scheduling program just be capable of acting upon each task in a sorted order of tasks, that is tasks which are given in a defined order from first to last, without modifying the given order of the tasks, and the ability to apply scheduling operations, unscheduling operations, and rescheduling operations to the sorted order of tasks.

In addition to the COMPASS scheduling program, the MICROSOFT PROJECT scheduling program also possesses such capabilities; and the scheduling programs described in U.S. Pat. No. 5,408,663 granted Apr. 18, 1995 to Miller, entitled Resource Allocation Methods, U.S. Pat. No. 5,233,533, granted Aug. 3, 1993 to Edstrom et al, entitled Method and Apparatus, and U.S. Pat. No. 5,093,794 granted Mar. 3, 1992 to Howie et al, entitled Job Scheduling Program, also appear to contain such capabilities.

It is noted that any scheduling programs found that do not contain the described capabilities can be modified by programmers to include them, if modification is possible. If the particular scheduling program selected by one wishing to practice this invention does not contain such a sort routine, however, such scheduling program must be modified to include one. As such sort routines are well known programming routines, such may easily obtained and incorporated

within the program with minimal effort. However, the preferred expedient is to chose a scheduling program as a base, which contains all those features or, if not, all those features, or all except the sort feature, the latter of which can easily be incorporated within any existing program with only minimal programming effort.

As is represented in block 1 of FIG. 1, with the foregoing general description of a known scheduling program as background, the scheduling program is run to formulate and/or define, as variously termed, a tentative schedule for the tasks. The program requests entry of the task data, which is entered into the program as data, manually via the computer's keyboard, scanned in via a scanner, or by any other conventional means of data entry. Thereupon the scheduling program executes, as upon the user's command.

The scheduling program is started in the conventional manner and calls for the entry of task data, represented at block 2. Each task entered into the computer for a project, includes information on the identification of the task I, such as "install pilot seat", task duration, D, the required resources, R, and the precedent constraints, P, applicable to the task.

As an example, one constraint may be that a certain task must be performed before another, a precedent constraint, such as, in the construction of an aircraft, the pilot's seat must be installed prior to installation of the pilot's overhead window or canopy. Thus before the canopy installation task can start, the scheduling program must look to determine whether the seat installation task is scheduled for completion and only then assign a start time for the canopy installation task. The COMPASS scheduling program ensures that the assignment of start time and completion time for each task in the project is consistent with and does not violate an applicable task priority constraint.

As is typical of scheduling programs, the inventory of available resources, RI, such as the manufacturing equipment, tools, human resources and skills, as called for by the scheduling program is entered in kind and quantity into the computer. The data on resources enables the scheduling program to allocate all available resources to the various tasks. In the event that a particular number of available resources is insufficient in quantity to allow accomplishment of all tasks simultaneously, as is typically the situation, in preparing the schedule the computer schedules the number of such resources as are available amongst the various tasks requiring the resource, in some preferred Heuristic order according to the algorithms forming the scheduling program. The scheduling program also ensures that the time allocations assigned to such resource for a task does not conflict with another task. That is, the resource is assigned to tasks without violating a resource constraint.

To avoid unnecessary detail in this application, it is not necessary to describe in this specification the steps in and/or source code programming of the known scheduling programs, such as COMPASS, and the algorithms forming such programs, since those are previously known to those skilled in the art, and those details are not necessary to an understanding of the present invention, which is an addition to and an improvement of such prior scheduling programs.

The computer thereupon processes the data in accordance with the steps prescribed in the scheduling program, carrying out the methodology prescribed in the scheduling program, and, following the expiration of the program's "execution time" completes the program's run and produces a schedule, S1, referred to, variously, as a tentative or preliminary schedule, represented by block 3.

The tentative schedule, S1, may be generally visualized by its individual elements as follows:

|            |                        |
|------------|------------------------|
| (1) Task A | S1, C1, D1, R1, P1, I1 |
| (2) Task B | S2, C2, D2, R2, P2, I2 |
| (N) Task n | Sn, Cn, Dn, Rn, Pn, In |

in which S is the start time, C is the completion time, D is the duration, R is the resource information, P is the precedence information and I is the identification of the task. That schedule is typically displayed on the computer's monitor, 8 in FIG. 4, and/or the associated printer 10 prints out the information.

From among the multiplicity of tasks in the project, the formulated schedule contains a task that begins no earlier than any other task in the project, the earliest start time. The schedule also contains another task that ends no later than any other task in the project, the latest completion time. The difference between those two times defines the cycle time for the project. Whatever the choice made for the basic scheduling program, it is assumed that the program produced has a "good" cycle time, one that appears reasonable, and that the scheduling program had a reasonable execution time; in other words it is a good quality program. Given a "good" cycle time, it is seen that the present improvement makes a better cycle time, thereby improving upon quality.

It is briefly noted that the foregoing is the state achieved by existing scheduling programs. There is no way of determining how "good" a schedule was achieved, unless one is able to demonstrate that another schedule can be created in a reasonable time that has a shorter cycle time. The only methods for such demonstration are to either use another program to construct a schedule to see if another algorithm might produce a better schedule, or to reorder the input data to see if another order for processing the given tasks might produce a better schedule.

In the next step the computer identifies the latest completion time for any of the tasks listed in schedule S1 and sets that completion time C, as the right boundary, Cc, which step is represented at block 5; and to identify the earliest start time for any of the listed tasks in that preliminary schedule and set that start time S as the left boundary Ss, which step is represented at block 7.

In the foregoing steps, the boundaries are set automatically by the scheduling program. The boundaries may, alternatively, be manually set by the user. In that event, the program should come to a halt and output to the display the appropriate message for the operator, as example, "Please insert the desired time desired for the right boundary? Note that the latest completion time of any task is (completion time)". The operator then enters the desired completion time via the computer keyboard. Following, the program next requests information on the left boundary in like manner with display of a similar query and the operator enters the desired start time boundary.

It is appreciated that the foregoing task listing S1 lists the tasks in no particular order, since such ordering is not required of a scheduling program and, hence, is not required by the known scheduling program upon which the present algorithms are imposed. Should by chance or design the prior scheduling program include such a feature, such as the scheduling programs earlier referred to, it is useful in the practice of the present invention, as next described.

The program sorts the listed tasks in chronological order by completion time C, as represented by block 9, to produce a chronological listing by completion time, S2.

It is appreciated that the tasks in this second list are the same in number, n, as in the first, but that the particular tasks listed in (a) above are not likely to be listed in the same order presented in the tentative schedule. Hence a different representation is given for the tasks in this sorted order. It should be understood, however, that each task in the first list, such as task B, finds a counterpart in the tasks of the second sorted list, Task AS as example, assuming only for purpose of illustration that the sort procedure reversed the positions of the first two tasks in the tentative schedule. The foregoing convention is used for each of the listings hereafter described.

It is recognized that the previously described time boundary setting steps may be accomplished prior to or following the sorting step, since neither step is dependent upon the other in function or precedent. That is a matter of designer's choice.

The algorithm next returns control and/or branches back, as variously termed to the main scheduling program to accomplish a shifting operation. Working in reverse chronological order in the chronological listing, starting with the last task in the list, that is, from the task with the latest completion time, each task is "right shifted" as much as is permissible to the right completion time boundary, as represented by block 11. That is, each task is unscheduled and rescheduled to start and finish as late as possible prior to or at the right time boundary, Cc, without violating any of the applicable constraints and requirements associated with the respective task. In making this shift and evaluating for resource conflicts, it is understood that the main scheduling program considers each task's duration, and, hence, the new start time as would be assigned to the respective task.

The foregoing backward shifting is accomplished by use of the capability of the underlying scheduling program, which is required to have the ability to perform "backward mode" scheduling, that is, to schedule tasks to start and finish as late as possible, and also the ability to perform "forward mode" scheduling, that is to schedule tasks to start and finish as early as possible, such as the capability found in at least the COMPASS scheduling program and the Microsoft Project scheduling program.

Each task is thus assigned a new completion time, C, and, based on the data respecting the duration required for the particular task, the task is assigned a new start time S. It should be noted that the "order" of the tasks in the "right shifted" task listing remains unchanged from the order in which those tasks appeared in the prior sort operation. However, the tasks may likely no longer be in chronological order as before, as a consequence of any reassignment of completion times. This task listing, S3, another temporary schedule of itself, may be represented as follows:

|             |                       |
|-------------|-----------------------|
| (1) Task AS | W1 (S, C, D, R, P, I) |
| (2) Task BS | W2 (S, C, D, R, P, I) |
| (3) Task nS | Wn (S, C, D, R, P, I) |

As those skilled in the art appreciate, the foregoing sort may also be accomplished by reversing the listing, an equivalent, by sorting the tentative task schedule in reverse chronological order by completion time and then selecting the first task in the list, which would then hold the latest completion date, and right shifting the first task in such listing for undergoing unscheduling and rescheduling, and continuing down through the task listing.

There are two subsidiary methods of performing the foregoing rescheduling step which may be conveniently

considered at this stage of the procedure, such as illustrated in the flow chart of FIG. 2 to which reference is made. One is to individually unschedule and reschedule each task, one by one, or, alternatively, unschedule all tasks and commence rescheduling with the last task in the completion time chronological order. In the first instance, the main scheduling program need deal with inserting one set of times, while the other task times remain fixed. In the latter the main scheduling program deals with the task data as raw, except for the order in which tasks are given reassigned times, which requires the scheduling program to run through a repeat "cycle time" to accomplish the result. Since the two sub-routines represent a slightly different situation for the main scheduling program, a slightly different schedule necessarily results when employing the latter subroutine in lieu of the former.

As illustrated by block 21 in FIG. 2 all tasks in chronological list S2 are unscheduled; a selection is made of the task in the latest completion time position in the chronological list as at block 23. As represented at block 25, the main schedule program then processes that selected task and reschedules it to the latest completion time permissible consistent with any applicable resource constraints and, based on the duration of the task, assigns a new start time also consistent with any applicable resource restraints; and places the task in a memory location for a new list in the last place location in the list as at block 27.

Checking to determine whether the processed task was the final task requiring completion as at decision block 29, and receiving a negative reply as at block 31, the main scheduling program next selects the task from the list that had the next to the latest completion time, as represented at block 33 and repeats, as at block 35, returning to the backward mode shifting, as at block 25, to process the task and assign the next task the latest available completion time, again consistent with any resource constraints. And the rescheduled task is entered in the next to last position in this new list. This process repeats, task by task, through the N tasks, until the decision at block 29 is affirmative, in which case the affirmative flag 37 pronounces the new revised list S3 complete as represented at block 39.

In the alternative procedure represented in part by the dash block outlines in FIG. 2, the task in the listing having the latest completion time position is selected as represented at block 22; and that selected task is unscheduled as represented at block 24; is processed by the main program, as at block 25, in the backward mode to determine the latest available completion time consistent with any resource constraints and a like start time also consistent with those constraints, which references as needed the various times still assigned to the other tasks whose start and completion times were not yet unscheduled, placing the task entry in the last position in a new list, as at block 27. As in the prior technique the program passes through the decisional block 29, the negative decision at 31 and the selection of the task in the listing having the next-to-last completion time position, as represented at block 33 and repeats at 35, processing this next task as at block 35 to right shift the task to the then latest available completion time as close as permissible to the completion time boundary Cc consistent with resource restraints, and assigns a new start time also consistent with resource constraints. This procedure continues, consecutively filling the new list, bottom to top, until an affirmative decision 37 occurs at block 37, indicating that all of the N tasks in the listing have been processed in the foregoing way and the program arrives at the revised listing S3 as at block 39.

Returning to the flow chart of FIG. 1 and continuing with the new algorithms, the various tasks listed in the "right shifted" task listing or temporary listing, S3, are again sorted, this time into chronological order by the respective start times, S to obtain another chronological listing, S4, represented in block 13. The first task in the listing S4 contains the earliest start time, S, and the last or "nth" task in the listing contains the latest start time.

This sorted listing, S4, which in itself is a schedule, may be represented as follows:

|             |                       |
|-------------|-----------------------|
| (1) Task AT | X1 (S, C, D, R, P, I) |
| (2) Task BT | X2 (S, C, D, R, P, I) |
| ...         |                       |
| (N) Task nT | Xn (S, C, D, R, P, I) |

Next, working in order in the list starting with the first task in the list, that is, with the task having the earliest start time, each task is "left shifted" as much as possible toward the start time boundary. That is, each task is unscheduled and rescheduled to occur at or as early as possible, but no earlier than the left or start time boundary or shortly thereafter, as desired, without violating any of the applicable constraints and requirements associated with the respective task. Thus each task is given a new start time, S, and, based on the data respecting the duration required for the particular task, the task is assigned a new completion time C. This creates a new listing, the "left shifted" task listing or schedule S5, represented in block 15, in which the tasks are maintained in the order set in the prior chronological listing.

This additional listing S5, which in itself is a schedule, is the schedule which is accepted by the program as the optimized schedule, and is represented as follows:

|             |                       |
|-------------|-----------------------|
| (1) Task AU | Y1 (S, C, D, R, P, I) |
| (2) Task BU | Y2 (S, C, D, R, P, I) |
| ...         |                       |
| (N) Task nU | Yn (S, C, D, R, P, I) |

As in the case of the right shifting, the left shifting of the tasks to the selected start time boundary may be accomplished in either of two subsidiary methods which are illustrated in FIG. 3, to which reference is made.

As illustrated by block 41 in FIG. 3 all tasks in chronological list S4 are unscheduled; a selection is made of the task in the earliest start time position in the chronological list as at block 43. As represented at block 45, the main scheduling program then processes that task and reschedules it to the earliest start time permissible consistent with any applicable resource constraints and, based on the duration of the task, assigns a new completion time also consistent with any applicable resource constraints; and places the task data in a memory location for another new list, as represented at block 47, in the first place location in the list.

Checking to determine whether the processed task was the final task requiring completion as at decision block 49, and receiving a negative as at block 51, the main scheduling program next selects the task from the list that had the next to the earliest start time, as represented at block 53 and repeats 55, returning to the forward mode shifting, as at block 45 to process the task and assign the next task the earliest permissible start time, again consistent with any resource constraints; and places the rescheduled left shift task in the next to the first position in the new list S5. This process repeats, task by task, consecutively filling the lower slots in the new list, until the decision at block 49 is

affirmative, in which case an affirmative flag 57 pronounces the new revised list S5 complete as represented at block 59.

In the alternative procedure represented in part by the dash block outlines in FIG. 3, the task in the listing having the earliest start time position is selected as represented at block 42; and that selected task is unscheduled as represented at block 44; that task is then processed by the main program in the forward mode, as represented at block 45, to determine the earliest start time consistent with any resource restraints and a like completion time also consistent with those restraints. In so doing the main scheduling program references as needed the various times still assigned to the other tasks whose start and completion times have not been unscheduled, placing the task entry in the first position in a new list, as at block 59. As in the prior technique the program passes through the decisional block 49, the negative decision at 51 and the selection of the task in the listing having the next-to-first start time position, as represented at block 53 and repeats as at block 55, processing this next task as at block 45 to left shift the task to the then earliest permissible start time as close as permissible to and no later than the start time boundary S<sub>s</sub> consistent with resource restraints, and assigns a completion time also consistent with resource constraints. This procedure continues until an affirmative decision occurs as at block 57, indicating that all of the tasks in the listing have been processed in the foregoing way and arrives at the revised listing S5 as at block 59.

Returning to FIG. 1, the new schedule S5 is the final step in the schedule optimization routine. The main schedule program then stores the schedule in memory, and overwrites or erases each of the original schedule and any intervening schedules as may have been produced and temporarily stored during the run of the scheduling program, which are not illustrated.

As additional steps to permit use of the schedule, the schedule is displayed on the computer's display device as represented at block 17, such as the associated computer monitor 8 and/or is printed out by the associated printer 10 represented in FIG. 4.

The optimizing program produces schedules of enhanced quality, that is, of lesser cycle time with at most a doubling of the execution time of the principal scheduling program. In one example, a schedule derived by the COMPASS scheduling program for performing a complex manufacturing project required 53 days for completion of the project. By subjecting that schedule to the additional algorithms presented in this specification, in just one run of the improved program, the schedule derived for the project required only 40 days for completion, a saving of 17 days time or 30%. Since the days saved represents considerable manufacturing overhead and money, the advantage and benefit of the improvement is apparent.

In general, applicant believes, that the modification should serve to improve all heuristic scheduling programs, moreso those scheduling programs that are regarded of poor quality and less so for those that are of higher quality. However, it is possible for a poor quality scheduling program to be modified to achieve the same quality as a higher quality program, but requires substantially less execution time to formulate the schedule.

Better quality schedules can often be produced by performing multiple repetitions of the basic right shift and left shift algorithm. Since this algorithm is designed to take an existing schedule, and by packing left and right, improve it,

one is permitted to take the result of a first application of the algorithm as the input to a second application of the algorithm, and take the output of a second iteration and use it as the input to a third iteration, and so on. Generally, no further improvement is found after just two or three iterations of the described procedure.

The foregoing algorithm can be used to improve a selected time frame within a schedule by setting the left and right time boundaries accordingly. As example, if one has a schedule for four weeks worth of work, and desires to be able to accommodate some additional work in the second week without perturbing the schedule for the first, third, or fourth week, one can set the left boundary to be the start time of the second week and the right boundary to be the end time of the second week and apply the shift right/left operations. If the schedule has not been previously packed, it should reduce the cycle time for the work scheduled in the second week, leaving room in the schedule to accommodate a small amount of additional work, perhaps ten to twenty per cent more, depending upon the quality of the initial schedule. The algorithm thus is used to open up a "hole" at a designated point in an existing schedule.

The algorithm can be used to open up a "hole" at a designated point in an existing schedule by applying the algorithm first with the left boundary set at the beginning of the schedule and the right boundary set at the designated point. Then only the right shift phase of the algorithm is applied with the left boundary set at the designated point and the right boundary set at the end of the schedule. Instead of just shifting left and right within a given week, as in the preceding example, one might choose to shift right everything from Wednesday of the second week through the end of the third week, and then shift left everything from the beginning of the first week through Wednesday of the second week in order to open up as much capacity in the middle of the second week as is possible. This allows one to clear a space in the work calendar to be able to accommodate an anticipated rush order that will be ready for handling at that time.

The algorithm can be used to improve the cycle time for a subset of the tasks on a schedule by setting the left and right boundaries accordingly and then applying the shifting operations only to the selected activities. As example, if a given schedule includes the production of several aircraft all at the same time, which are in various stages of completion, one may desire to accelerate the completion of one aircraft, while leaving the others approximately as they are. To do so, one sets the left boundary to be the scheduled start time of the selected aircraft and set the right boundary to be the scheduled finish time of the selected aircraft and apply the described shift right/left operations to ONLY the steps of the selected aircraft, leaving the steps associated with the other aircraft unchanged, then the scheduling for the selected aircraft will be able to take advantage of any excess capacity within exactly that time frame. As another more interesting example, if given two aircraft being constructed according to a given schedule with interleaved operations, one may select the aircraft with the lower priority and shift its operations right, towards its completion time, and then select the high priority aircraft and shift its operations towards its start time. Then, in order to exploit any excess capacity that might remain, the full shift right/left procedure is performed only for tasks associated with the high priority aircraft. Again the results obtained depend largely upon the quality

of the original schedule that is input to the algorithms. If one starts with a high quality schedule, the amount of movement obtained, that is, quality improvement, is small.

If the underlying scheduling program contains the ability to sort by additional or secondary keys, additional useful variations of the described algorithm are possible; and it is also useful if the scheduling program provides the ability, as an option, to schedule, unschedule and reschedule individual activities.

As example, if one computes the slack time for each activity in a given schedule, as hereafter described, and then sorts by two keys before the right pass, first, sorting by slack time from least to greatest, and then sorting by completion time from last to first, then if two tasks complete at the same time, the one with the least slack time will be shifted first. If one applies this additional sort key on both right and left passes, one obtains greater schedule improvement than when just sorting by completion and start times. The reason for this is that jobs with less slack time are more critical. By giving those jobs priority in the shifting process, they tend to shift into better locations on the schedule. Since they are the critical jobs they have more influence over the resulting cycle time.

The best way to determine the slack time associated with a task is to perform the schedule pack algorithm twice. The first time squeezes out the majority of the excess cycle time. Then during the second pack, if one carefully records how much a task moves during the left shift phase one obtains a very clear measure of slack time. Remember the task was shifted as far right as possible and then on the left pass, shifted as far left as possible. Anything that is truly critical will not move. Other tasks will move either a little or a lot.

Although the last described features are desirable for the underlying scheduling program, it is recognized that the foregoing options are not required for implementation of the basic algorithm.

Although the present application adopts the terminology of tasks and project, other terminology may be used without departing from the invention. As example others may refer to tasks as "activities" and to the project as the "task"; still others may refer to the tasks as "nodes" and to the project as a "principal node". Notwithstanding the choice of terminology employed, the steps in the described algorithm, by whatever name, remains as "sweet".

The underlying theory to the shifting procedure is recognized as being intuitive. In general, the first tasks placed on a schedule benefit from the flexibility in their choice of time and resources. Tasks placed on the schedule later in the scheduling process are left with only the times and resources that earlier activities did not use.

The sort procedures combined with the right and left phases, is believed to implicitly give higher priority to the right activities, while constructing the right shift and left shift schedules. When a schedule is built in the forward direction every task is scheduled to start and finish as early as possible. Because of that, critical activities in the left part of the schedule are crowded together with many other non-critical activities. But the right most activities on the schedule are found in that part of the schedule, because they follow critical activities in the left part of the schedule, and most are themselves critical.

In the right shift phase, these right-most critical activities are effectively given first priority in building the new right-shifted schedule. By similar analysis, the left-most activities in the right-shifted schedule are critical activities with little

slack time and they are given first priority in the left shift phase. Between the two passes, the present algorithm gives first priority to the placement of critical activities at the right and then the left ends of the schedule, while allowing non-critical activities to shift freely in between. The foregoing also allows one to understand why using the additional sort key of slack time generally improves the performance of the algorithm.

The foregoing algorithms are seen to define a novel method for optimizing an existing computer assisted scheduling program. When permanently integrated within the source code of an existing computer assisted scheduling program a new and improved scheduling program is seen to result. The invention therefore may be seen also as a new

scheduling program. The physical data defining that program may be carried upon a floppy disk or other computer peripheral memory device through which the method may be installed upon a programmable digital computer. In that

sense the invention is also a program element. With the invention installed within a computer, either a general purpose computer in which the algorithms are installed from a program element, commonly referred to as software, or a special purpose computer dedicated to scheduling in which the algorithms are permanently installed within a read only memory, in that sense the invention is also a computer apparatus that performs the algorithm. All of the foregoing arrangements thus fall within the scope of my invention.

In the foregoing description, the word "time" was used to indicate either a starting point, such as start time, and/or an ending point in a schedule, such as completion time. On a calendar schedule that time would likely be expressed in terms of a calendar date and an hour or in terms of a number of twenty four hour periods following an arbitrary start date and hours, which renders the display of a schedule more easily understood by the operator. However, to minimize complication to this description, the convention used is to simply designate those dates and hours solely by the word "time".

The foregoing invention has been demonstrated as successful, having been embodied within a computer program and applied. An unpublished source code listing for that program, authored by the applicant, copyrighted by the

McDonnell Douglas Corporation, written in the ADA language, accompanies this application in an Appendix hereto. That source code listing illustrates programming details of the described algorithm for implementation as an enhancement within the copyrighted COMPASS scheduling program. That source code listing is not available for publication or reproduction. While, it is appreciated that the foregoing description is sufficient in detail to enable one skilled in the art to make and use the invention, such unpublished source code listing may be inspected in the file of this application by those who wish to acquaint themselves with a specific example of a code listing that incorporates the described invention.

While a preferred embodiment has been illustrated and described herein, it will be obvious that numerous modifications, changes, variations, substitutions and equivalents, in whole or in part, will now occur to those skilled in the art without departing from the spirit and scope contemplated by the invention. Accordingly, it is intended that the invention herein be limited only by the scope of the appended claims.

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**APPENDIX**  
**COPYRIGHT (UNPUBLISHED)- MCDONNELL DOUGLAS CORP.**  
**Schedule Pack Source Program**

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PROCEDURE schedule_pack (Activitylist : IN OUT Activity_List.Typeactivitylist;
    Resourcelist : IN OUT Resource_List.Typeresourcelist;
    Conditionlist : IN OUT Condition_List.Typeconditionlist) is
    minimum_start_time: time.type time := time.positive_infinity;
    maximum_finish_time: time.type time := time.negative_infinity;
    scheduling_window: interval.typeinterval;
    forward_mode : mode.type mode := mode.strict_forward_mode;
    backward_mode : mode.type mode := mode.strict_backward_mode;
    workingactivitylist: activity_list.typeactivitylist;
    workingresourcelist: resource_list.typeresourcelist;
    workingconditionlist: condition_list.typeconditionlist;
    localactivitylist: activity_list.typeactivitylist;
    localresourcelist: resource_list.typeresourcelist;
    localconditionlist: condition_list.typeconditionlist;
    localactivity: activity.typeactivity;
    localstart : time.type time;
    localfinish : time.type time;
    temp_activity_list: activity_list.typeactivitylist;
begin
    workingactivitylist := activitylist;
    workingresourcelist := resourcelist;
    workingconditionlist := conditionlist;
    localactivitylist := activitylist;
    localresourcelist := resourcelist;
    localconditionlist := conditionlist;
    abstract_io.write_string(low_level_io.standard_output_file,"*****Optimizing Schedule*****");
    abstract_io.write_newline(low_level_io.standard_output_file);
    minimum_start_time := interface.accept_time("Left Boundary for Packing Operation");
    abstract_io.write_string(low_level_io.standard_output_file,"Scanning Schedule for Right Boundary");
    abstract_io.write_newline(low_level_io.standard_output_file);
    -just a reminder that we need to change both sp and ccp to work on just selected activities
    Qualified_Name_Prefix(resource_name, Resource_Profile.Qualifiedname_Of
    (Localresourceprofile) while not activity_list.nilp (localactivitylist) loop
    localactivity := activity_list.first(localactivitylist);
    if activity.assigned_of(localactivity)then
        localfinish := activity.assigned_finish_of(localactivity);
        if localfinish>maximum_finish_time then
            maximum_finish_time := localfinish;
        end if;
        end if;
        localactivitylist := activity_list.rest(localactivitylist); end loop;
    scheduling_window := interval.make(minimum_start_time,maximum_finish_time);
    -first pack to the right, within the current bounds
    -interface.display_message ("note", "sorting by status = completed");-- completed at the bottom
    Abstract_lo.Write_String (Low_Level_lo.Standard_Output_File,"sorting by status = complete");
    Abstract_lo.Write_Newline (Low_Level_lo.Standard_Output_File);
    temp_activity_list := Sort_Commands.Sort_By_Status
    (workingActivityList,completed_id);
    activity_list.shallow_collect(workingactivitylist);
    workingactivitylist := temp_activity_list;
    -interface.display_message ("note", "sorting by precedence");
    Abstract_lo.Write_String (Low_Level_lo.Standard_Output_File, "sorting by precedence");
    Abstract_lo.Write_Newline (Low_Level_lo.Standard_Output_File);
    temp_activity_list := Sort_Commands.Sort_By_Predecessors (workingActivityList);
    activity_list.shallow_collect(workingactivitylist);
    workingactivitylist := temp_activity_list;
    -interface.display_message ("note", "sorting by assigned finish time");
    Abstract_lo.Write_String (Low_Level_lo.Standard_Output_File, "sorting by assigned finish time");
    Abstract_lo.Write_Newline (Low_Level_lo.Standard_Output_File);
    temp_activity_list:= Sort_Commands.Sort_By_Assigned_Finish_time
    (workingActivityList);
    activity_list.shallow_collect(workingactivitylist);
    workingactivitylist := temp_activity_list;
    -interface.display_message ("note", "sorting into reverse order");
    Abstract_lo.Write_String (Low_Level_lo.Standard_Output_File, "sorting into reverse order");
    Abstract_lo.Write_Newline (Low_Level_lo.Standard_Output_File);
    temp_activity_list := Sort_Commands.Reverse_order (workingActivityList);
    activity_list.shallow_collect(workingactivitylist);
    workingactivitylist := temp_activity_list;
    -interface.display_message ("note", "sort for right pass complete");

```

-continued

**APPENDIX**  
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**Schedule Pack Source Program**

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```

Abstract_lo.Write_String (Low_Level_lo.Standard_Output_File, "sort for right pass
complete");
Abstract_lo.WriteLine (Low_Level_lo.Standard_Output_File);
localactivitylist := workingactivitylist;
Interface.Display_Activity_List(workingActivityList);
abstract_io.write_string(low_level_io.standard_output_file, "packing right");
while not activity_list.nilp (localactivitylist) loop
  localactivity := activity_list.first(localactivitylist);
  if activity_assigned_of(localactivity) and then
(id.equal(activity.status_of(localactivity),completed_id) or
id.equal(activity.status_of(localactivity),inwork_id) or
id.equal(activity.status_of(localactivity),pending_id)) and then time.>""
(activity.assigned_finish_of(localactivity), minimum_start_time) then localstart := 
activity.assigned_start_of(localactivity);
  --time.write_dshm
(low_level_io.standard_output_file,activity.assigned_start_of(localactivity));
  scheduling_primitives.Unschedule
(localactivity,workingactivitylist,workingresourcelist);
  scheduling_primitives.schedule
(localactivity,workingactivitylist,workingresourcelist,workingconditionlist,
  scheduling_window, backward_mode);
if activity_assigned_of(localactivity) then
if time."=" (activity.assigned_start_of(localactivity), localstart ) then
abstract_io.write_string(low_level_io.standard_output_file,"=");
elsif time. ">" (activity.assigned_start_of(localactivity), localstart ) then
abstract_io.write_string(low_level_io.standard_output_file,>__);
elsif time. "<" (activity.assigned_start_of(localactivity), localstart ) then
abstract_io.write_string(low_level_io.standard_output_file,<__);
abstract_io.write_string(low_level_io.standard_output_file,"warning, failed to pack on
right pass");
Qualified_name.write(low_level_io.standard_output_file,xactivity.qualifiedname_of
(localactivity)); abstract_io.write_string(low_level_io.standard_output_file,"Old Time:");
time.write_dshm (low_level_io.standard_output_file,localstart);
abstract_io.write_string(low_level_io.standard_output_file,"New Time:");
time.write_dshm
(low_level_io.standard_output_file,activity.assigned_start_of(localactivity));
abstract_io.WriteLine (low_level_io.standard_output_file);
end if;
else
  abstract_io.write_string(low_level_io.standard_output_file, "failed to reschedule on
right pass");
  Qualified_name.write(low_level_io.standard_output_file,xactivity.qualifiedname_of
(localactivity)); abstract_io.write_string(low_level_io.standard_output_file,"Old
Time."); time.write_dshm (low_level_io.standard_output_file, localstart);
  abstract_io.write_newline (low_level_io.standard_output_file);
end if;
end if; localactivitylist := activity_list.rest(localactivitylist);
end loop;
-- then see which ones pack back to the left
-interface.display_message ("note", "sorting by status = completed");
Abstract_lo.WriteLine (Low_Level_lo.Standard_Output_File, "sorting by status =
completed");
Abstract_lo.WriteLine (Low_Level_lo.Standard_Output_File);
temp_activity_list := Sort_Commands.Sort_By_Status
(workingActivityList,completed_id);
activity_list.shallow_collect(workingactivitylist);
workingactivitylist := temp_activity_list;
-interface.display_message ("note", "sorting into reverse order");
Abstract_lo.WriteLine (Low_Level_lo.Standard_Output_File, "sorting into reverse
order");
Abstract_lo.WriteLine (Low_Level_lo.Standard_Output_File);
temp_activity_list:= Sort_Commands.Reverse_order (workingActivityList);
activity_list.shallow_collect(workingactivitylist);
workingactivitylist := temp_activity_list;
-interface.display_message ("note", "sorting by predecence");
Abstract_lo.WriteLine (Low_Level_lo.Standard_Output_File, "sorting by predecence");
Abstract_lo.WriteLine (Low_Level_lo.Standard_Output_File);
temp_activity_list := Sort_Commands.Sort_By_Predecessors (workingActivityList);
activity_list.shallow_collect(workingactivitylist);
workingactivitylist := temp_activity_list;
Abstract_lo.WriteLine (Low_Level_lo.Standard_Output_File);
temp_activity_list := Sort_Commands.Sort_By_Assigned_Start_Time
(workingActivityList);

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## APPENDIX

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activity_list.shallow_collect(workingactivitylist);
workingactivitylist := temp_activity_list;
-interface.display_message ("note", "sort for left pass complete");
Abstract_io.WriteString (Low_Level_io.Standard_Output_File, "sort for left pass
complete");
Abstract_io.WriteLine (Low_Level_io.Standard_Output_File);
localactivitylist := workingactivitylist;
Interface.Display_Activity_List(workingActivitylist);
abstract_io.writeString (low_level_io.standard_output_file, "packing left");
abstract_io.write_newline (low_level_io.standard_output_file);
while not activity_list.nilp (localactivitylist) loop
local activity := activity_list.first (localactivity list);
if activity.assigned_of (localactivity) and then
(id.equal (activity.status_of (localactivity), completed_id) or
 id.equal (activity.status_of (localactivity), inwork_id) or
 id.equal (activity.status_of (localactivity), pending_id)) and then
time.>= (activity.assigned_finish_of (localactivity), minimum_start_time) then
localstart := activity.assigned_start_of (localactivity);
--time.write_dshm
(low_level_io.standard_output_file, activity.assigned_start_of (localactivity));
scheduling_primitives.Unschedule (localactivity, workingactivitylist, workingresourceclist);
scheduling_primitives.schedule
(localactivity, workingactivitylist, workingresourceclist, workingconditionlist,
 scheduling_window, forward_mode);
if activity.assigned_of (localactivity) then
if time.=< (activity.assigned_start_of (localactivity), localstart) then
abstract_io.writeString (low_level_io.standard_output_file, "=");
elseif time.< (activity.assigned_start_of (localactivity), localstart) then
abstract_io.writeString (low_level_io.standard_output_file, "<");
elseif time.> (activity.assigned_start_of (localactivity), localstart) then
abstract_io.writeString (low_level_io.standard_output_file, ">");
abstract_io.writeString (low_level_io.standard_output_file, "warning, failed
to pack on left pass");
Qualified_name.write (low_level_io.standard_output_file, activity.qualifiedname_of
(localactivity));
abstract_io.writeString (low_level_io.standard_output_file, "Old Time:");
time.write_dshm (low_level_io.standard_output_file, localstart);
abstract_io.writeString (low_level_io.standard_output_file, "New Time:");
time.write_dshm
(low_level_io.standard_output_file, activity.assigned_start_of (localactivity));
abstract_io.write_newline (low_level_io.standard_output_file);
end if;
else
abstract_io.writeString (low_level_io.standard_output_file, "failed to
reschedule on left pass");
Qualified
name.write (low_level_io.standard_output_file, activity.qualifiedname_of (localactivity));
abstract_io.writeString (low_level_io.standard_output_file, "Old Time:");
time.write_dshm (low_level_io.standard_output_file, localstart);
abstract_io.write_newline (low_level_io.standard_output_file);
end if;
end if;
localactivitylist := activity_list.rest (localactivitylist); end loop;
activitylist := workingactivitylist;
resourceclist := workingresourceclist;
conditionlist := workingconditionlist;
exception
when Interface.Oops=> raise;
when others=>
abstract_io.writeString (low_level_io.standard_output_file, "exception raised while
packing!");
activity.write (low_level_io.standard_output_file, localactivity);
abstract_io.write_newline (low_level_io.standard_output_file);
raise;
end schedule pack;

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What is claimed is:

1. A computer assisted method of optimizing a preliminary schedule for performing a plurality of scheduled tasks that collectively complete a project, said preliminary schedule specifying no less than a start time, a completion time, identification, and resource requirements for each of the

<sup>60</sup> plurality of tasks in which any constraints associated with each resource are respected and the plurality of tasks complies with constraints on the order of performance of any one task relative to other tasks defined in the schedule, which includes the step of:

- (a) inspecting completion times for said plurality of scheduled tasks in said preliminary schedule and determining latest completion time of any of said scheduled tasks;
- (b) defining a completion time boundary, said boundary comprising a time equal to or later than said latest completion time;
- (c) inspecting said start times for each of said plurality of scheduled tasks in said preliminary schedule and determining the earliest time of any of said plurality of scheduled tasks;
- (d) defining a commencement time boundary, said boundary comprising a time at least equal to and no later than an earliest commencement time;
- (e) sorting said plurality of scheduled tasks in said preliminary schedule into chronological order by completion times to derive a temporary chronological listing comprising the completion times for each task;
- (f) following said sorting and commencing with one of said tasks in said temporary chronological listing having said latest completion time and continuing with the remaining ones of said tasks in reverse chronological order by completion time
- (f1) rescheduling each task in said temporary chronological listing to a new completion time that is as close to said completion time boundary as is permissible without violation of any constraint associated with such task and, based on the duration of respective tasks, to a new start time, said rescheduling being without violation of any constraint associated with such task, whereby each task is assigned a new completion and start time to create a first revised temporary listing of tasks arranged in the order found in said derived temporary listing; and,
- (g) sorting said plurality of tasks in said first revised temporary listing into chronological order by commencement times to derive a second temporary chronological listing comprising the start times for each task;
- (h) commencing with one of said tasks in said second temporary chronological listing having the earliest start time and continuing with the remaining ones of said tasks in ascending chronological order by start time,
- (h1) rescheduling each task in said second temporary chronological listing to a new start time that is as close to said commencement time boundary as is permissible without violation of any constraint associated with such task and, based on the duration of said respective tasks to a new completion time, said rescheduling being without violation of any constraint associated with such task, whereby each task is again assigned a new start time and completion time to create a third listing of tasks arranged in the same order found in said second temporary chronological listing, said third listing of tasks comprising an optimized schedule.
2. The method as defined in claim 1, wherein the step (f1) of rescheduling includes the step of:
- (f1)(a) unscheduling all tasks in said temporary chronological listing by removing the associated start and completion times thereof prior to assigning a completion time for any of said tasks.
3. The method as defined in claim 1, wherein the step (f1) of rescheduling includes the steps of:
- (f1) (a) removing the associated start time of the task having the latest completion time;

- (f1) (b) rescheduling said respective tasks to a new completion time that is as close in time period to said completion time boundary as is permissible without violating any constraint associated with said tasks; and,
- (f1) (c) based on the respective duration of said respective tasks, assigning a new start time for said respective tasks without violating any constraint associated with said tasks; and
- (f1) (d) repeating steps (f1) (a) through (f1) (c) in reverse chronological order by completion time for each of said tasks.
4. The method of claim 1, further including the computer assisted method of generating said schedule for optimizing which comprises the steps of:
- (1) listing no less than the identification of and the duration time anticipated for completion of each of said plurality of tasks necessary to complete said project and, with respect to each of said tasks, any constraints associated therewith, including, for each respective task, the identification of any other task that requires completion prior to commencement of the respective task and any resources required by said respective task; and
  - (2) formulating a preliminary schedule for performance of said plurality of tasks, in which each of said tasks is completed without violation of a respective associated constraint, said preliminary schedule, including, for each of said tasks, at least a start time and a completion time.
5. The method as defined in claim 1, further comprising the steps of accepting the optimized schedule derived from steps (a) through (h) and repeating thereon steps (a) through (h) to derive a further optimized schedule.
6. The method as defined in claims 1, 2, 3, 4 or 5, further comprising the step of displaying said optimized schedule.
7. A programming element for an electronic digital computer comprising a programming medium and program data means resident on said medium for actuating a computer to execute a method as set forth in claims 1 or 4.
8. A computer assisted method of generating a schedule for performing a plurality of scheduled tasks that collectively complete a project, said method being carried out with the aid of a programmed computer, said method comprising the steps of:
- (1) listing no less than the identification of and the duration time anticipated for completion of each of a plurality of tasks necessary to complete said project and, with respect to each of said tasks, any constraints associated therewith, including, for each respective task, the identification of any other task that requires completion prior to commencement of the respective task and any resources required by said respective task; and
  - (2) formulating a preliminary schedule for performance of said plurality of tasks, in which each of said tasks is completed without violation of a respective associated constraint, said preliminary schedule, including, for each of said tasks, at least a start time and a completion time;
  - (a) inspecting each of said completion times for said plurality of scheduled tasks in said preliminary schedule and determining the latest completion time of any of said tasks scheduled therein;
  - (b) defining a completion time boundary, said boundary comprising a time equal to or later than said latest completion time;

- (c) inspecting each of said start times for each of said plurality of scheduled tasks in said preliminary schedule and determining the earliest start time of any of said plurality of scheduled tasks therein;
- (d) defining a commencement time boundary having an earliest commencement time, said boundary comprising a time at least equal to and no later than said earliest commencement time;
- (e) sorting said plurality of scheduled tasks in said preliminary schedule into chronological order of the respective completion times of each of said tasks to derive a temporary listing of completion times for each task in descending chronological order, wherein the first task initially scheduled for completion in said plurality of scheduled tasks appears first in said listing and the last task initially scheduled for completion in said plurality of scheduled tasks appears last in said listing;
- (f) commencing with said last task in said temporary listing and continuing through said temporary listing in reverse chronological order of completion times,
- (f)(1) unscheduling the respective preliminarily scheduled tasks by removing the associated start and completion times; and
- (f)(2) rescheduling the respective tasks to a new completion time that is as close in time period to said completion time boundary as is permissible without violating any constraint associated with said tasks; and,
- (f)(3) based on the respective duration of said respective tasks, assigning a new start time for said respective tasks, to define a second temporary listing in which said tasks are ordered in the same order as in said first named temporary listing;
- (g) sorting said plurality of tasks in said second temporary listing into chronological order of the respective start times of each of said tasks to derive a further temporary listing of start times for each task in descending chronological order of start times, wherein the first task initially scheduled for commencement in said plurality of tasks in said second temporary listing appears first in said further temporary listing and the last task initially scheduled for commencement in said plurality of tasks in a right shift task temporary listing appears last in said further temporary listing;
- (h) commencing with the first task in said further temporary listing and continuing through said further temporary listing in chronological order of commencement times,
- (h)(1) unscheduling the respective scheduled task and,
- (h)(2) rescheduling the respective tasks to a new commencement time that is as close in time to a left boundary as is permissible without violating any constraint associated with such respective task; and
- (h)(3) based on the respective duration of said respective task, assigning a new completion time for said respective tasks, to define an optimized schedule of tasks for completion of a given task.

9. The method as defined in claim 8, further comprising the step of displaying said optimized schedule.

10. A programming element for an electronic digital computer comprising a programming medium and program data means resident on said medium for actuating a computer to execute a method as set forth in claim 8.

11. A computer assisted method of generating a schedule for performing a plurality of scheduled tasks that collec-

- tively complete a project, said method being carried out with the aid of a programmed computer, said method comprising the steps of:
  - (1) listing no less than the identification of and the duration time anticipated for completion of each of a plurality of tasks necessary to complete said project and, with respect to each of said tasks, any constraints associated therewith, including, for each respective task, the identification of any other task that requires completion prior to commencement of the respective task and any resources required by said respective task; and
  - (2) formulating a preliminary schedule for performance of said plurality of tasks, in which each of said tasks is completed without violation of a respective associated constraint, said preliminary schedule, including, for each of said tasks, at least a start time and a completion time;
    - (a) inspecting said completion times for said plurality of scheduled tasks in said preliminary schedule and determining the latest completion time of any of said scheduled tasks;
    - (b) defining a completion time boundary, said boundary comprising a time equal to or later than said latest completion time;
    - (c) inspecting said start times for each of said plurality of scheduled tasks in said preliminary schedule and determining the earliest time of any of said plurality of scheduled tasks;
    - (d) defining a commencement time boundary, said boundary comprising a time at least equal to and no later than said earliest commencement time;
    - (e) sorting said plurality of scheduled tasks in said preliminary schedule into chronological order by completion times to derive a first temporary chronological listing comprising the completion times for each task;
    - (f) following said sorting and commencing with one of said tasks in said temporary chronological listing having said latest completion time and continuing with the remaining ones of said tasks in reverse chronological order by completion time
      - (f1) rescheduling each task in said temporary chronological listing to a new completion time that is as close to said completion boundary time as is permissible without violation of any constraint associated with such task and, based on the duration of said respective tasks, to a new start time, said rescheduling being without violation of any constraint associated with said tasks, whereby each task is assigned a new completion and start time to create a first revised temporary listing of tasks arranged in the order found in said first derived temporary listing; and,
      - (g) sorting said plurality of tasks in said first revised temporary listing into chronological order by commencement times to derive a second temporary chronological listing comprising the start times for each task;
      - (h) commencing with one of said tasks in said second temporary chronological listing having the earliest start time and continuing with the remaining ones of said tasks in ascending chronological order by start time,
        - (h1) rescheduling each task in said second temporary chronological listing to a new start time that is as close to said commencement boundary time as is

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permissible without violation of any constraint associated with said tasks and, based on the duration of said respective tasks, to a new completion time, said rescheduling being without violation of any constraint associated with said tasks, whereby 5 each task is again assigned a new start time and completion time to create a third listing of tasks arranged in the same order found in said second temporary chronological listing, said third listing of tasks comprising an optimized schedule.

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12. A computer assisted method of optimizing a preliminary schedule for performing a plurality of scheduled tasks that collectively complete a project, said preliminary schedule specifying a start time and a completion time that define a respective duration, said preliminary schedule respecting any constraints associated with each task including constraints on the order of performance of any one task relative to other tasks, the method including the steps of:

defining a completion time boundary no earlier than the latest completion time of any of said scheduled tasks;

defining a commencement time boundary no earlier than the earliest start time of any of said plurality of scheduled tasks;

rescheduling each task such that the completion time for each task is rescheduled to a first new completion time that is as close to said completion time boundary as is permissible without violation of any constraint associated with such task, wherein said rescheduling step further alters the start time for each task based on the duration of each respective task to define a first new start time such that each task is assigned a first new completion time and a first new start time as a result of

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said rescheduling step to thereby create a revised temporary listing of tasks;

further rescheduling each task such that the first new start time for each task is rescheduled to a second new start time that is as close to said commencement time boundary as is permissible without violation of any constraint associated with such task, wherein said rescheduling step further alters the first new completion time for each task based on the duration of each respective task to define a second new completion time such that each task is assigned a second new completion time and a second new start time as a result of said further rescheduling step to thereby create a listing of tasks comprising an optimized schedule.

13. The method as defined in claim 12 further comprising the step of unscheduling all tasks in said preliminary schedule by removing the associated start time and completion time for each task prior to the initial step of rescheduling each task.

14. The method as defined in claim 13, wherein said initial step of rescheduling each task includes the steps of:

removing the associated start time of each task;  
rescheduling the completion time for each tasks to a first new completion time that is as close in time period to said completion time boundary as is permissible without violating any constraint associated with said tasks; and

rescheduling the start time associated with each task based on the duration of each task to a first new start time without violating any constraint associated with said task.

\* \* \* \* \*